The United Correspondence Schools....

...New York...

Instruction Paper.

Subject:

Geometrical Drawing.

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GEOMETRICAL DRAWING.

1. Drawing is the art of representing objects by means of lines. The entire subject may be divided into two general classes; **free-hand drawing,** when no instruments of precision are used, and **mechanical** (me-chan'ic-al) **drawing,** in which, in order to obtain great accuracy, tools are employed for an exact representation of an object in its actual size or according to a given scale. These classes may again be subdivided in various ways, as, for example, free-hand drawing into **sketching** and **designing,** and mechanical drawing into **architectural** (ar-chi-tec'tur-al) **drawing, geometrical** (ge-o-met'ric-al) **drawing**, and **machine drawing.**

While the final objects to be attained by a practice of these three kinds of drawing may differ considerably, they are all dependent on a correct use of the instruments and a thorough knowledge of geometrical principles. For this reason we shall first take up these two subjects.

INSTRUMENTS AND DRAWING MATERIALS.

2. While a draughtsman may find it convenient to provide himself with a large number of drawing instruments, only those mentioned in this Paper are of vital importance and are ample in number for the satisfactory execution of all the drawings in this course.

The **drawing-board** should be made of well-seasoned pine, free from knots, and must have a smooth surface. For the work in this course the size of the board is 16 by 21 inches, and its thickness about $\frac{5}{8}$ of an inch. Drawing-boards are made of different sizes and construction to suit the sizes of the drawings and the requirements of the draughtsman or designer. Boards should be barred or doweled at the ends to stiffen them and resist any tendency

to twist, as well as to afford a suitable edge for the working of the **T** square. Instead of this method, cross-bars on the back of the board are preferred by many draughtsmen. These serve for the twofold purpose of strengthening the board and raising it from the table, which facilitates the moving of it. The cross-bars or cleats are dovetailed into the board, and are tapered along their length so that they can be driven into place, as shown in Fig. 1. The left-hand edge of the board should be carefully trued, and no other edge should be used for the head of the **T** square to rest against.

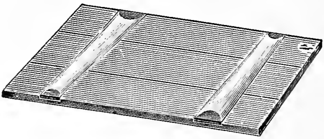


FIG. 1.

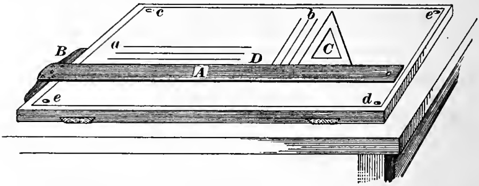


FIG. 2.

Fig. 2 shows a drawing-board with cross-bars, and also illustrates the position of the paper, **T** square, and triangle.

3. The **T square,** shown in Fig. 3 and in position in Fig. 2, should only be used for drawing horizontal lines. It

FIG. 3.

is usually made of mahogany or cherry-wood, and consists

of two parts, *A*, the blade, and *B*, the head. These two may be permanently attached to each other, or the head may be movable for drawing inclined lines. The resetting of it, however, takes time and often causes inaccuracy. The head of the **T** square is held against the left-hand edge of the board, as shown in Fig. 2, and the **T** square is moved with the left hand until the upper edge, *D*, of the blade *A* is very near to the point through which the line is to be drawn. All the lines *a*, drawn thus, will be horizontal and parallel if the student holds his pencil in a vertical position. Be sure to hold the head of the **T** square tightly against the edge of the board, and never stand a **T** square on the floor; it should be hung up. Never use the edge of the blade for a cutting edge, nor the head of the **T** square for a hammer.

4. The **Triangles.** These are used for drawing vertical lines and lines making definite angles with the horizontal. For this purpose triangles are divided into 45° and 60° triangles, shown in Fig. 4 and Fig. 5 respectively. The 45° triangle has two angles of 45° each and one of 90°; the 60° triangle has one angle of 60°, one of 30°, and one of 90°. To draw a vertical line, lay the triangle *C* against the blade of the **T** square so that a right angle is formed, as shown in Fig. 2. The **T** square is held tightly against the board with your left hand, and the triangle brought in position with your right. Then hold the blade and triangle lightly with your left hand, keeping them from slipping, and draw the line *b* with a pen or pencil held in your right hand. For drawing lines making angles of 30°, 45°, or 60° with the blade of the **T** square, the triangles are placed in such a position as to have the required angles next to the upper edge of the blade.

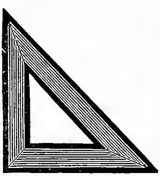


FIG. 4.

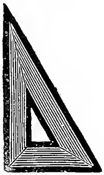


FIG. 5.

5. Through a given point, to draw a line parallel to a given line. Should the line be horizon-

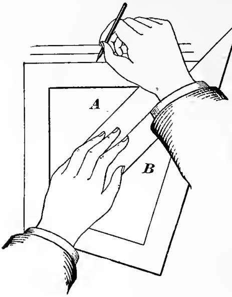


Fig. 6.

tal or vertical the **T** square and triangles are used, but if the line has an inclined direction triangles only are made use of. They are held in the position shown in Fig. 6, the long edge of one resting against the long edge of the other. Both *B* and *A* are moved about until one edge of *A* corresponds with the given line. *B* is then held down with the left hand, and *A* is moved along the long edge of *B* until the edge which was coincident with the given line passes through the given point, when a line is drawn through that point.

If a number of lines are to be drawn parallel to the given line, *B* is held down as shown in the figure and *A* is moved along the long edge of *B*. Should the lines occupy a space in excess of the distance through which *A* can be moved, hold *A* down with your left hand and move *B* with your right until the new position of the triangles will permit the drawing of the required lines.

6. To draw lines perpendicular (per-pen-dic′u-lar) **to others which are neither horizontal nor vertical.**

This method is similar to the one described in **Art. 5,** with the exception that the edge *mn* of *A* is made to coincide with the line *c* or *d*, as shown in Fig. 7. The long edge of triangle *B* is then laid against the long edge of *A*, and *B* is held down firmly. *A* is then

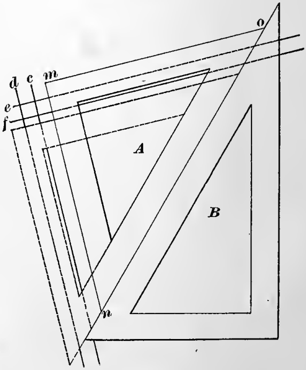


Fig. 7.

moved along with the left hand into the position shown by the dotted lines, when e and f can be drawn along the edge mo. These lines will be perpendicular to c and d.

Before beginning to draw the first plate the student should practise the handling of the **T** square and triangles, understanding the scope of their usefulness, and their manipulation.

7. The **compasses** (com′pass-es) with its accessories, the divider-points, pen, pencil, needle-point, and lengthening bar, as shown in Fig. 8, are, next to the instruments described, the most important tools of a draughtsman. Compasses are used for drawing circles or arcs, large or small, with pencil or ink; and if the steel points are inserted in the sockets of the legs of the compasses, as shown in Fig. 8, the instrument becomes a pair of dividers, which are used for laying off distances or for dividing straight lines or circles into parts.

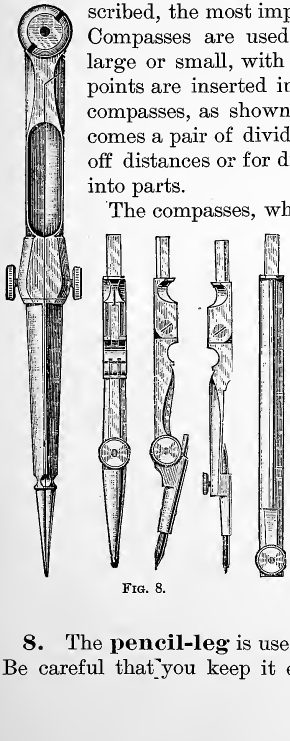


Fig. 8.

The compasses, when used for drawing circles or as dividers, should be held between the thumb and forefinger of the right hand. When laying off distances, or dividing lines or circles, turn the dividers alternately to the right and left, varying the distance between the points until the required distance is obtained. The points on the dividers should be very sharp, so as not to make holes in the paper, which, besides looking ugly, are small receptacles for the ink.

8. The **pencil-leg** is used for drawing arcs, circles, etc. Be careful that you keep it exactly the same length as the

needle-point. This is accomplished by drawing the pencil out a little after each sharpening. The method of sharpening the pencil will be treated in Article 17.

9. The use of the **inking-leg,** as its name implies, is to repeat the pencil work in ink; the ink must be India ink and waterproof. On examining the pencil- as well as the inking-leg, you will find a joint in them, the purpose of which is to enable you to bend the leg at that point, so that the part which contains the ink (in the inking leg) may be kept perpendicular to the surface of the paper whilst describing a circle, as is shown in Fig. 9. If the inking-leg would be kept as

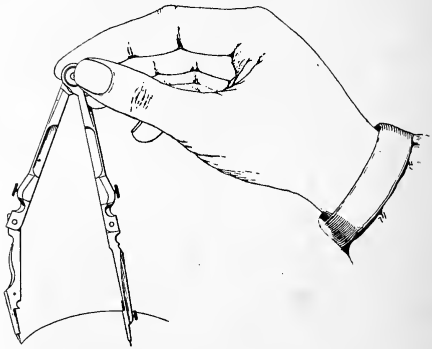


Fig. 9.

straight as the one carrying the needle-point, when the compasses are opened to any extent only one of the nibs (the inner one) will touch the paper, and thus the outer edge of the circle drawn will be ragged and rough. In drawing circles be careful to bear as lightly as possible on the part carrying the needle-point, so that your center is not pricked through the paper; for then, as each concentric circle is drawn, the hole will become larger, until all chance of following the exact curve will be lost, and when you come to

ink the drawing you will find the difficulty still further increased.

10. When it is required to draw a circle with a larger radius than could be described with the compasses in their usual form, a **lengthening** (length'en-ing) **bar** is used; this is an extra extension rod, which fits into the socket of the leg of the compasses, and has at its other end a socket into which the end of the pencil-leg or inking-leg fits. This forms a pair of compasses with one leg very much longer than the other, and which is, therefore, rather awkward to manage. Here again the student is reminded that the pencil-leg and inking-leg must be bent at the joint, so that they may be perpendicular to the surface of the paper.

11. The following hints will be found useful:

(1) See that the needle-points as well as the divider-points of your compasses are round, and not triangular, which latter form makes a hole much larger than the former does.

(2) See that this point is not too fine; it should be rather a blunt point than otherwise, only just sharp enough to prevent it slipping away from the center.

(3) Should either of these faults exist they may be easily remedied by drawing the point a few times over an oil-stone, remembering to keep turning it around whilst moving it along.

(4) If the joint at the top of the compasses is troublesome to open, or it works too freely, it should be adjusted by means of the accompanying key until it works easily and can be manipulated with one hand *only*. The joints in the pen- and pencil-legs should be adjusted by means of the screwdriver, which is part of the key. Be sure that the joints do not open or close by the weight of the parts, as this action will open or close your compasses, and the circumference of the circle which you are drawing will not be continuous.

(5) Learn at the outset how to open and close the compasses with one hand, as it is unnecessary and looks awkward to use both hands for the handling of so small and delicate

a tool as a pair of compasses. A draughtsman is judged as much by the condition and handling of his instruments as he is by the work which he performs with them.

12. The compasses are, however, not well adapted for drawing small circles and arcs, on account of their size and weight. For this work, as well as for the drawing of a number of circles of the same size, the **bow-pencil** and **bow-pen**, shown in Fig. 10, are used. The legs of these instruments, instead of being united by a hinge joint, are made in one piece so as to form a spring, which by its action tends to force the points apart; they are acted upon by a nut, which, screwing upon a bar fixed in one leg and passing through the other, as shown in Fig. 10, enables very delicate adjustments to be made. The two legs of the instrument should be adjusted to very nearly the same length, the needle-point projecting a trifle beyond the pen- or pencil-point so that very small circles may be drawn.

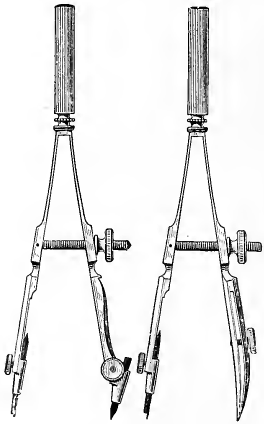


FIG. 10.

To open or close either one of the instruments, put the needle-point in position and press down slightly on the top of it with the forefinger of the right hand. Then turn the adjusting nut with the thumb and middle finger of the same hand.

13. The most frequently used, and, we might also say, misused, instrument is the **drawing-pen,** or, as it is sometimes called, the *ruling-* or *right-line pen,* shown in Fig. 11. It is similar to the inking-leg of the compasses just described, and is used for inking in straight lines and irregular curves. It consists of the nibs, the handle, which is made of ivory

or ebony, and a needle-point which is attached to the upper part of the handle and is screwed into the lower part of the blades. The pen should be held nearly upright, with the forefinger resting on the head of the screw, as shown in Fig. 12. This is a natural po-

FIG. 11.

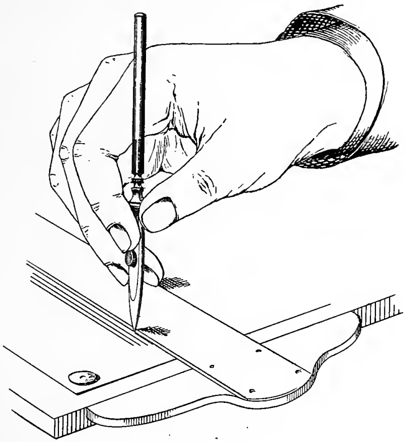


FIG. 12.

sition, and the student will have no difficulty in holding the pen in the above manner after a little practice. Do not rest the wrist on the board or **T** square, but hold it in the position shown in Fig. 12, from which it will be seen that only two fingers move along the blade of the **T** square.

14. In order to draw a smooth, even line, the student should observe three things :

(1) Hold the pen perpendicular to the board, so that both nibs touch the paper. If one blade only rests on the paper the line will be ragged.

(2) Do not press the inner blade against the edge of the **T** square, as this will cause the two blades to close up and

the line will be thinned at that point. The edge of the **T** square should be used as a guiding edge only.

(3) The ink must flow freely. If the ink has become dry, wipe it off with cloth and put new ink into the pen, or run a piece of paper between the blades. It is always safe, after a few moments delay, to try the pen on another piece of paper before a line is made on a drawing.

Never put a drawing-pen away without first cleaning it thoroughly. To accomplish this conveniently the set screw which adjusts the width of the lines should be taken out and the blades be separated. For this purpose there is a joint at the bottom of the blades.

The ink should be placed between the nibs with a quill or pen; under no circumstances should the pen be dipped into the ink. Be sure to wipe off all the ink from the outside of the blades, for if there is any ink on the blade which rests against the edge of the **T** square the student is almost sure to make a blot.

15. Drawing-Ink. The best India ink should be used for inking in a drawing, and "Higgins' Waterproof Liquid India Ink," shown in Fig. 13, is recommended to our students. To the cork of every bottle of this ink a quill is attached, which should be used for filling the pen. This is done by dipping the quill into the ink and then inserting it between the blades of the drawing-pen. Too much ink in the pen is liable to drop, and the pen when refilled should not contain more ink than will occupy the space of a quarter of an inch along the blades. **Again, be sure not to have any ink on the outside of the blades.** Do not use common writing ink, as it corrodes the drawing-pens and does not dry as quickly as India ink. Drawings on which writing ink has been used will not be accepted.

FIG. 13.

The quick-drying quality of liquid India ink will annoy the student considerably, as the ink will dry in the pen in a very brief time and refuse to flow. This is especially the

case when fine lines are being drawn, and the only remedy is to clean the pen frequently and then refill it. If you want to stop working for a while, or have completed an evening's work, be sure to clean your pen thoroughly and open the blades so as to remove the strain on them. Never use a knife for scraping off the hardened ink, and if you use water be sure to wipe off all the moisture before the pen is put into the case. It often happens that the ink has dried only at the extreme points of the blades ; all that is required to start it flowing is to wet the end of the finger and apply it to the points of the pen. To avoid the spilling of the ink, and to prevent its drying up or filling up with dust, it is essential that you keep the bottle corked whenever you are not filling your pen.

If the ink should require to be thinned or diluted, use a mixture of clear water and ammonia—four drops of ammonia to the ounce of water.

16. Drawing-Paper and how to fasten it to the board. For the drawings in this course the student requires Whatman's hot-pressed drawing-paper, demy size, which is 15″x20″. This paper is of excellent quality, well adapted for ink work, and will withstand considerable erasing. Four thumb-tacks are used for securing the paper to the drawing-board, one at each corner of the sheet. The first thumb-tack inserted is the one marked *c* in Fig. 2, about $\frac{1}{4}$″ from the upper and left-hand edge of the paper. The **T** square is then placed near the top edge of the paper, which is moved until the top edge is parallel with the blade of the **T** square. The thumb-tack marked *d* is then inserted, the paper being stretched diagonally across the board. Thumb-tacks *e* are then pushed in, and you are ready to begin your drawing.

17. Drawing-Pencils and how to sharpen them. As a rule hard pencils are not the best for mechanical drawings which are to be inked, as they are liable to make grooves in the paper, the bottom of which the nib of the drawing-pen does not touch, and hence the edges of the

line will be ragged; and, further, lines which are drawn with very hard pencils are difficult to rub out. We recommend the use of a No. 4 Dixon's pencil, marked H, which indicates its hardness. For mechanical drawing it is best to have a flat point on the pencil, as shown in Fig. 14. This is done by cutting away the wood and leaving about $\frac{1}{4}$ of an inch of lead projecting, which is then to be cut until it is thinned to a flat, broad point like a chisel, with the lower edge slightly rounded. The broad side of this point is moved along the edge of the T square or triangle, and the line thus drawn will be found to be much finer than one drawn with a round point. The chisel point is economical in various ways, for it will not break easily, and the point once cut can be rubbed from time to time on a fine piece of sandpaper or file, or even the edge of the drawing-paper. The lead in the compasses should be sharpened in a similar manner, but with a narrower edge, and should be so inserted in the pencil-leg that only one line is drawn with the same radius and center whether the compasses be moved in one direction or the other. The student should learn to make light lines and under no circumstances wet the point of his pencil.

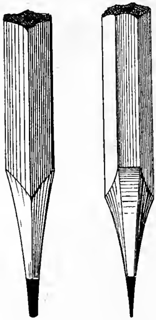


FIG 14.

18. Erasers (e-ras'ers) **and how to clean a drawing.** To the beginner, a pencil- and ink-eraser are tools with which he cannot very well dispense, but their incorrect or excessive use will ofttimes disfigure an otherwise creditable drawing. The less either one of the erasers is used the better it will be for the paper, and the pencil eraser should not be used until the entire drawing, with the exception of the hatched portions, letters, and figures, is inked in. Then rub out as lightly as possible all pencil lines which have not been inked over and any other disfigurements on the paper. For erasing ink lines a sharp knife blade may be used instead of the ink eraser. In either case the paper should be smoothed

down with the back of the finger nail or a bone handle, if ink is to be applied at that particular spot. Remember in all your work that prevention is better than cure, and it is more advisable to do your work slowly and with care than to do it quickly and disfigure the drawing by using the erasers excessively.

19. The draughtsman's **scale,** unlike the ordinary two-foot rule, is made of boxwood and has its divisions marked on beveled edges, so that measurements may be made by applying the scale directly to the drawing. Its divisions do not begin at the two ends, but some distance away, so as to avoid any error which might be introduced by the wearing away of the ends of the scale. The scales are either flat or triangular; but there should never be more than two scales on each edge of the instrument, one at each end. Drawings are either made **full size** or to a **scale.** The working-drawings of details should be made to as large a scale as convenient, and, if possible, should be full size. The smaller scales are used for the general views of large objects. For full-size drawings the edge marked *A* (Fig. 15) should be used, which is divided into twelve inch-divisions, which are subdivided into halves, quarters, eighths, and sixteenths.

20. Suppose it is required to make a drawing $\frac{1}{4}$ size, or to have 3 inches on the drawing represent 1 foot on the object. If we then lay off 3 inches and let those represent 1 ft., then $\frac{1}{12}$ of these 3 inches, or $\frac{1}{4}$ of an inch, will represent 1 inch on the object. Such a scale is laid off at *B*, and should be used in the following way:

Suppose we wish to lay off a distance on the drawing equal to $2'—5\frac{1}{2}''$ on a *scale of 3 inches to one foot*, or a *quarter scale*, we begin at the zero mark on the side marked *B* (Fig. 15) and lay off the distance which corresponds to $2'$ on one side of it and the $5\frac{1}{2}''$ on the other. For this purpose the zero mark is not placed at the end of the scale, but a distance from the end which represents one foot. A scale of $1\frac{1}{2}$ *inches to one foot*, or an *eighth scale*, is laid off at the end marked *C*, and this is used in a similar manner as the one

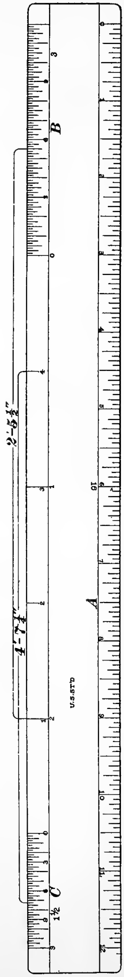


FIG. 15.

quarter or any other scale. If it is required to lay off 4′—7¼″, we lay off 4 ft. (represented by 6 inches on our scale) on one side of the zero mark, and 7¼ inches on the other, as is shown in Fig. 15.

After the student understands this principle and has practised the use of scales for a long time, he is in a position to construct a scale for a particular purpose at any time.

If, for example, a *one-twelfth scale*, or a scale of 1 inch to one foot, is wanted, the student can lay off 1 inch on a strip of paper and divide that into 12 parts. Then each one of these 12 parts represents one inch on the object. These can again be subdivided into halves and quarters if it is found necessary.

For a *sixteenth scale*, or a scale of ¾ *inch to one foot*, it is only necessary to let the 1½ inches on the eighth scale represent two feet on the object; and for a *twenty-fourth scale*, or a scale of ½ *inch to one foot*, halve each dimension on the scale of 1 inch to one foot.

The above represent the most common scales used in practice, and a correct understanding of them will enable the student to make a drawing to any desired scale.

21. Irregular (ir-reg′u-lar) **curves,** or, as they are sometimes called, "French curves" or "sweeps," are rulers of irregular shapes used for drawing curves other than arcs of circles. The curve should be so constructed (see Fig. 16) that by means of it a curve of any shape can be drawn. It is used in the following way: A certain number of points have been determined through which a curve is to be drawn. Find some part on your irregular curve which will pass through at least

FIG. 16.

three of the points, and draw the curve through them, taking care, however, that the termination has such a direction that the next part of the curve joined to it will not form an unsightly point at the junction. Also be sure that the line does not curve out between the points, or, perhaps, has a tendency to curve in. In placing the curve in a new position, let the last part of the curve just drawn be retraced by the first part of the curve in the new position. It is advisable, especially if the points are a considerable distance apart, to sketch the curve free-hand and then to let the penciled curve act as a guide for the irregular curve. All curves should be penciled in before they are inked.

We will illustrate the method of using the irregular curve by an example. Let it be required to draw a curved line through the points *a*, *b*, *c*, *d*, etc. (Fig. 17).

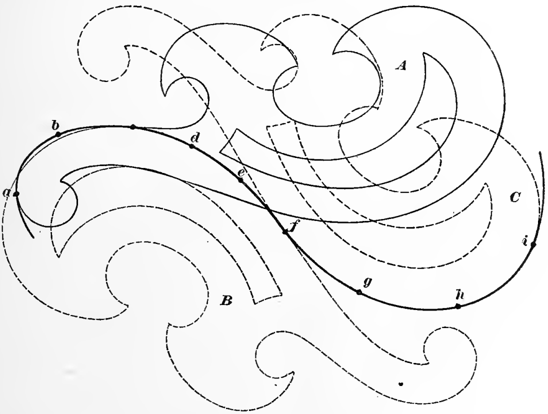


FIG. 17.

We first place the curve in the position marked *A*, so that part of it joins the points *a*, *b*, and *c*. We draw this section *a*, *b*, *c*, or rather stop at some place between *b* and *c*, so that there will be no angle where the next part of the curve will join it. We then place the curve in the position *B*, shown

dotted in Fig. 17, and find that it retraces part of the distance *bc*, and joins the points *c*, *d*, *e*, and *f*. We draw this section of the curve to some point between *e* and *f*, and place the curve in the position *C*. Here we again retrace part of *ef*, and complete the curve by joining *f*, *g*, *h*, *i*. It will be noticed that the curvature changes at the point *f*, and at such a point the curve may be joined without retracing a section of it on either side.

The student should practise the joining of points with irregular curves, first sketching them free-hand, then penciling them by adjusting the irregular curve to the free-hand curve, and, lastly, inking them, taking care to hold the pen close to the curve and always in the direction of the curvature.

22. The **protractor** (pro-tract'or), one form of which is illustrated in Fig. 18, is an instrument used for laying off or measuring angles and dividing circles into any number of equal parts, or laying off degrees on the circumference. Pro-

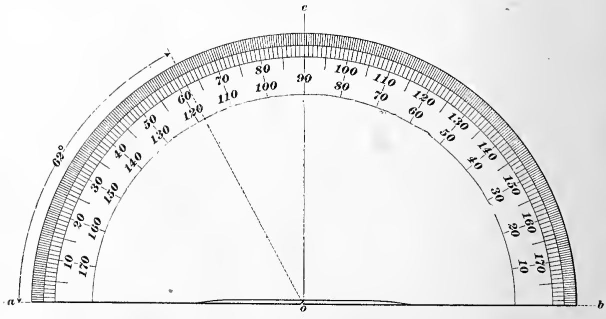


FIG. 18.

tractors are made either of metal, paper, or some transparent material. The semicircle which is its one boundary, the diameter of the circle with the marked center being the other, is divided into 360 parts, each part being one-half of one degree. It is numbered from *a* to *b* and *b* to *a* from 0 to 180

degrees. To use the protractor for measuring or laying off angles we proceed as follows:

One side of the angle which we intend to lay off has the direction *ab* (Fig. 18), and the vertex is located at the point *o*. Making the lower edge of the protractor, or rather the line passing through the 0° and 180° mark, coincide with line *ab*, or *ab* prolonged, of the proposed angle, and placing the center, *o*, of the protractor over the point which is to be the vertex of the angle, we lay off the required number of de-

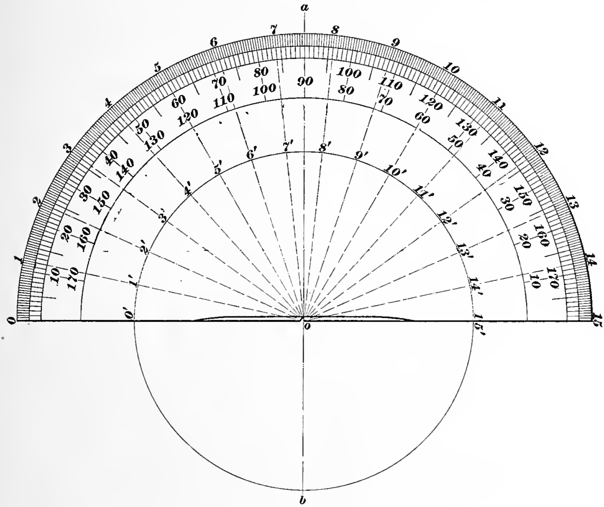


Fig. 19.

grees, as, for example, 62° shown in the figure. A mark is then made at this place with a sharp-pointed pencil, and, after the protractor has been removed, the mark is joined to the vertex *o*. It is advisable for greater accuracy to prolong the line *ab* so that both the 0° and the 180° mark will coincide with the line.

For dividing the circumference of a circle into any number of equal parts, say 30 (see Fig. 19), the point *o* on the pro-

tractor is placed directly over the center of the circle, and the line joining the 0° and 180° marks is made to coincide with the diameter of the circle, or the diameter prolonged as is shown in the figure. The diameter *ab* is also prolonged and will coincide with a line joining the center, *o*, and the 90° mark on the protractor. We then lay off on the semi-circumference of the protractor 12 divisions, as 0-1, 1-2, 2-3, etc., giving us 15 parts. These points are then joined by lines to the center of the circle, as shown in Fig. 19, cutting the circumference of the circle in the points 0′, 1′, 2′, 3′, etc.

23. In conclusion, the student is urged to remember that the mere possession of a case of instruments, however good, will not constitute a draughtsman. The instruments are merely the tools—the mechanical agents through which the mind acts; and it cannot be denied that the more thoroughly the mind comprehends the object to be drawn, the more willing and intelligent servants will the hands become, and the more accurately will they guide the compasses or the drawing-pen. The student will, no doubt, find it difficult at first to draw very fine lines, or to get them to intersect each other exactly as required, especially if he has been engaged in some hard manual occupation during the day; but he will find a little practice will soon overcome this, if he but starts with patience, energy, and the earnest desire to excel.

LETTERING THE DRAWINGS.

24. Lettering may be divided into two general classes, namely, **mechanical** and **free-hand.** These are again divided into different styles of letters, and the proper choice of class and style, as well as their correct execution, is one of the most difficult problems for the beginner. However, drawing-office experience has shown that the free-hand letter and the style shown below should be used for all lettering on a mechanical drawing, except the title, which should be made with the **T** square and triangles, and the style adopted should be the one called **block lettering.**

The student must be told at the outset that unsightly

lettering will not only spoil an otherwise excellent drawing, but will also confuse and discourage the workman who is obliged to use the drawing. A draughtsman should acquire a definite style of lettering and use this throughout his work. Ordinary script or poorly executed lettering will not be accepted, and the student will find the time he devotes to practising how to letter profitably spent.

He should do his lettering without haste, and not be discouraged if he finds that the lettering of a drawing consumes more time than the making of the drawing itself. This is often the case on drawings of details, and even the most experienced draughtsman will devote all the time that is required to the careful execution of his letters and figures.

The style of lettering which we have adopted, and which is shown in Fig. 21, has been approved by the leading manufacturing concerns in this country, and we have found that any student who does his work conscientiously can easily reproduce these letters and do them neatly and rapidly without the use of instruments. For lettering, a Gillott's No. 303 writing-pen should be used, such as is shown in Fig. 20. The height of the capital letters is $\frac{3}{32}$ in., and that of the small letters is $\frac{2}{3}$ of this, or $\frac{1}{16}$ in. They should not be any larger or smaller than this.

Fig. 20.

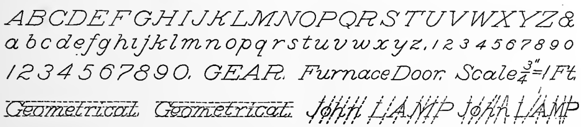


Fig. 21.

25. After the student has decided what lettering ought to be placed on his drawing, and where it should be placed (two questions of great importance), he draws the guide lines for the tops and bottoms of the letters with a **T** square, the required distance apart, as stated above. These lines should be penciled as lightly as possible, since they are to be erased

after the lettering has been inked in. Be sure not to have the tops and bottoms of the letters extend beyond or fall short of the guide lines. If the student fails to observe this point the lettering will look like the second word "Geometrical" in Fig. 21.

26. Another important point to be observed is to give all letters the same inclination.

As will be seen by inspecting the letters of the words "John Lamp" following the word "Geometrical" in Fig. 21, their sides all have the same slant, which should be 60°, as is indicated by the dotted lines. The two sides of the letters *N*, *M*, *n*, *u*, etc., are parallel and have the common slant of all the letters. At the beginning the student is advised to draw a number of parallel slant lines, which will aid him in keeping the inclination uniform.

27. Each letter, or rather set of letters, in this system has its own particular construction, and this should be carefully studied by the student. For convenience of study, and on account of the principles involved in their construction, we will divide the capital letters into four sets, as is shown in Fig. 22.

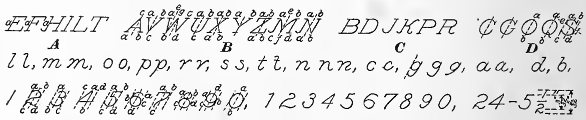


FIG. 22.

In the first set, ***A***, which includes the letters *E*, *F*, *H*, *I*, *L*, *T*, we deal simply with horizontal lines and lines having the common slant, and the main points to be observed are to have the inclination uniform and to have the horizontal lines coincide with the guide lines. The lines marked *a* in the letters *E*, *F*, and *H* are drawn midway between the upper and lower guide lines, and the left-hand side in the letter *H* is slightly curved at the bottom.

In set **B** we include those letters which are constructed about a center line having the inclination of the common slant line. The student should make the points *a* and *b* in these letters, and *a* and *g* in the *W*, an equal distance from the center lines, and in *A* and *V* this distance is to be $\frac{3}{64}$ in., making the width of these letters $\frac{3}{32}$ in. In both letters the student should first draw the common slant and then draw the sides, as explained above. It will be seen that the side *cb* in the letter *A*, and *ac* in *V*, are nearly perpendicular to the guide lines.

To make any letter in this set, the common slant line, which is also the center line, must first be drawn. The upper part of the *Y* begins a little below the center, and the points *a* and *b* are a little less than $\frac{3}{64}$ in. distant from the center line, so as to make the width of the letter $\frac{5}{64}$ in. at the top.

The student should not attempt to make the *U* with one stroke of the pencil or pen. First make the line *ac*, beginning at *a*, and then draw *bc*, beginning at *b*.

The sides *ac* and *bd* of the letter *M* are parallel, have the common slant, and *ac* is curved a trifle at the bottom, as shown. The letter is $\frac{3}{32}$ in. wide, and is, therefore, as wide as it is high. The student should first draw the two sides *ac* and *bd*. Then draw the line *ef* half-way between them, and join *a* and *b* with *f*. The lines *af* and *bf* are slightly curved.

The letter *W* is composed of two *V*'s, each narrower at the top than the letter *V*. The line *eb* is first drawn, having the common slant; then the points *a* and *g* are laid off $\frac{1}{32}$ in. from *e*, and the lines *ab* and *gb* are drawn. The part *gdc* is drawn in a similar manner. The entire letter is, therefore, $\frac{1}{8}$ in. wide; *ab* and *gd*, as well as *gb* and *cd*, are parallel, and *ab* and *gd* are nearly perpendicular to the guide lines.

The letters *U*, *X*, *N*, and *Z* are made $\frac{5}{64}$ in. wide, the *X* and *Z* being a trifle less than this at the top. The student should observe that the small horizontal lines in which some of the sides of the letters terminate should be horizontal and exactly in line with the guide lines. They should not be omitted from letters on which they belong, nor should they

be placed on letters where they do not belong. Let the student be guided by the letters as they are shown in Fig. 22.

The letters in the set ***C*** are combinations of straight and curved lines, and the main feature to be observed here is the fulness of the curves and the proper width and slant of the letters.

In the set marked ***D*** in Fig. 22, those letters are shown which are composed entirely of curves, namely, *C*, *G*, *O*, *Q*, and *S*.

The general inclination of these letters is the same as for all the others, and the student should make a line having the common slant, to guide him in the construction of these letters. The *C* and *G* can be made with one stroke of the pencil or pen. The *O* and *Q* should be made in two strokes, the first from *a* to *b* on the left of the common slant line, and the second from *a* to *b* on the right of it. The *S* can be made in one stroke, from *b* to *c*. The student should draw the two slant lines *ac* and *bd*, and have the letter *S* touch these lines at *a*, *d*, and *c*, and not at *b*. As a guide for the middle portion of the letter, the line *ef* is drawn, which should not have a greater slant than is shown in the figure.

28. Again referring to Fig. 21, the student will notice that the *b*, *d*, *h*, *i*, *j*, *k*, *l*, and *p* have sharp corners at the top, and that the *q* is sharp at the bottom; all of them terminate in a small horizontal line which coincides with the upper guide line in all the letters named except the *q*. All small letters have the common slant and should be constructed carefully and in strict accordance with the copy in Fig. 21. The first letter of each group in the middle line of Fig. 22 is printed correctly, and the ones following show a construction which should be avoided by the student.

The letter *g* should be constructed as shown, the upper and lower loop touching the common slant line, which should be drawn for a guide by the beginner. The *s* is printed similar to the capital *S*. The *d* should be made in two strokes and the *b* in one.

In conclusion, we want to say that all lettering should first be done with pencil and then with pen and ink. The student should do his lettering slowly, and practise the style and con-

struction of the letters on a sheet of paper before he attempts to put them on his drawing. The letters should be spaced evenly and should all have the same inclination.

29. Again referring to Fig. 22, the student should study the construction of the numbers and make them exactly like the copy shown there. The workman in the shop, as well as the builder, is guided in the construction of apparatus or dwellings by the dimensions which he finds on the drawing. It is, therefore, of the utmost importance that the numbers indicating the size of a particular part on a drawing should be plainly written. Adopt the style shown in Figs. 21 and 22. They all have the same general slant as the letters and should be constructed as follows :

The first set of numbers in the last line of Fig. 22 shows the figures as they should be printed. The student will observe that all the numbers except the 1 and 4 are constructed about a center line which has the common slant (60°), and that the curves in the numbers 2, 3, 5, 6, 8, 9, 0 are full and round. The 1 is made in one stroke. The 2 touches the two parallel slant lines at four points. The 3 touches them only at three points, as shown. The line *ab* in 4 is drawn from a point *a* located at about $\frac{1}{3}$ of the distance between *c* and *d*. The 5 has three points in contact with the slant lines, and the line *ab* is straight and coincident with the upper guide line. The 6 touches the slant lines at three points and should be drawn in two strokes—the first from *a* to *d*, and the second from *b* to *c* and joining the first curve at *d*. The point *c* in the 7 should fall midway between the point *a* and the center line. The line *ab* should be straight and *bc* curved. The 8 should touch the slant lines at two points, and the upper loop should be slightly smaller than the lower. It should be made in two strokes, the first being the same as the letter *s*, that is, *b*, *a*, *d*, *c*. The second stroke is from *b* to *c*, completing the number. The 9 touches the slant lines at three points, and the upper loop extends a little below the center of the two outside guide lines. This number is made by beginning at some point between *b* and *d* and drawing the loop *dab*; then, beginning at the first starting point, the rest of the number is drawn. The back of

the numbers 6 and 9 should be curved lines and only touch the slant line at one point marked *b*. The 0 is made in two parts, beginning each part at *a* and joining them at *b*.

The second set shows the numbers as they should not be made, and the student should avoid these mistakes : Do not affix a small line to the 1, and be sure to give it the common slant. Do not make the lower part of the 2 too large. Do not cramp the numbers, as shown in 3, 4, 8, 9, and 0, but make the curves full and round. The horizontal line in the 4 should be drawn a trifle below the center of the two outside guide lines. The lower loop of the 5, and the upper loop of the 6, should not protrude as they do in these specimens. The line connecting the two outer guide lines in the 7 should not be straight, but should have a double curve, as shown in the first set.

The height of the numbers is $\frac{3}{32}$ in., the same as the capital letters, and in case we have a fraction, as is shown in Fig. 22, the total height of the fraction is $\frac{5}{32}$ in., each number being a little less than $\frac{1}{16}$ in. high.

30. For the titles of all the plates and for large headings, the block letters, shown in Fig. 23, are used.

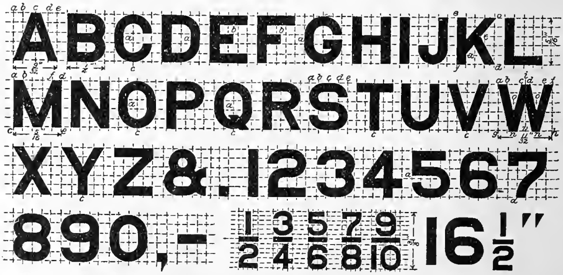


FIG. 23.

The letters are made with **T** square, triangles, and compasses, and the *only* free-hand work about them is the filling in of the spaces between the lines made with the draw-

ing-pen. An ordinary writing-pen may be used for this purpose.

The student first draws two horizontal lines $\frac{5}{16}$ in. apart; this space he divides into five spaces of $\frac{1}{16}$ in. each, which gives him the guide lines for the tops, bottoms, and centers of the letters. He then draws two vertical lines $\frac{1}{16}$ in. apart (see *a* and *b* in the figure); $\frac{1}{8}$ in. from *b* he draws the vertical line *d*, and $\frac{1}{16}$ in. from this the line *e*, making the total width of the letter $\frac{1}{4}$ inch. This is the width of all the letters, with the exception of the M, which is $\frac{5}{16}$ in. wide; the W, which is $\frac{11}{32}$ in. wide; the I, which is $\frac{1}{16}$ in. wide; the A, which is $\frac{9}{32}$ in. wide; and the J, which is $\frac{3}{16}$ in. wide. The distance between any two letters is $\frac{1}{16}$ in., except where P and F precede A; where J follows F, P, T, V, W, or Y; where V, W, or Y follow L; and where A is adjacent to T, V, W, or Y. In these cases the lower extremity of one letter is in the same vertical line with the upper extremity of the other.

After the student has laid out his horizontal and vertical guide lines which give him the width, height, and thickness of the letters, as well as the spaces between them, he will find the remaining work very simple. However, we will point out a few details which deserve special attention. The parts marked *a* in the letters C, D, G, O, and Q are flat, this being due to the fact that the letters are higher than they are wide. In the letters A, V, W, and Y draw a line midway between the outside vertical lines, which is marked *c* in the letter A. On each side of this line lay off $\frac{1}{32}$ in., which gives a width of $\frac{1}{16}$ in. to the tops and bottoms and very nearly $\frac{1}{16}''$ to the stems of these letters. The P, R, B. D, and S are flat at the top, and the last three also on the bottom. To construct the W, first draw two vertical lines, *ag* and *fh*, $\frac{11}{32}$ in. apart. Midway between these draw the line *iv* and lay off the points *c* and *d* $\frac{1}{32}$ in. on each side of *i*. Midway between *ad* and *cf* draw the lines *o*, *n*, and measure off $\frac{1}{32}$ in. on each side of the points *n*. Then complete the W by joining these points with *a*, *b*, *c*, *d*, *e*, and *f*.

To construct the M, draw the two vertical lines *ac* and *de*

$\frac{5}{16}$ in. apart, and midway between these draw a line. $\frac{1}{32}$ in. on each side of this line, on the lower guide line lay off two points and join these with the points *a* and *d*. From *b* and *f* draw lines parallel to these, and then complete the letter by drawing the vertical and horizontal lines with **T** square and triangle.

The three straight horizontal portions of the letter S are joined on the upper left and lower right by semicircles, and at the upper right and lower left quadrants form the ends of the letter.

After the vertical lines of the letter K have been drawn, the line *ab* is drawn from the point *a*, located on the first horizontal division line from the bottom, to *b*, the upper right-hand corner of the letter. *c* is located midway between the lines *ef* and *bd* on the second horizontal division line from the top. *d* is located vertically below *b*.

The width of the letters E and F is four spaces, as is the case with all the letters except those mentioned above. The points *b* in E and F are located midway between the outer extremities of the letters, or two and a half spaces to the right of the first vertical line.

After these few explanatory remarks the student should have no difficulty in constructing the other letters by having frequent reference to Fig. 23.

31. The height and width of the numbers in this system of lettering are the same as those of the letters, namely, $\frac{5}{16}$ in. and $\frac{1}{4}$ in. respectively.

The construction of the numbers should require no further explanation after the student has mastered the construction of the letters. He should frequently refer to Fig. 23 and diligently study each number. Carefully observe the curvature of the numbers 2 and 7, and in the number 5 notice that the point *a* is located $2\frac{3}{4}$ spaces from the top of the number.

The total height of the fractions is $\frac{3}{8}$ in., and the height of each number $\frac{5}{32}$ in. The width of these numbers is $\frac{1}{8}$ in.

The "and" sign and punctuation marks should also be carefully studied and practised.

In filling in the spaces between the lines made with the

drawing-pen, use a pen that does not scratch or tear up the fibres of your paper; and use your drawing-ink for this purpose, not plain writing-ink.

HOW TO SEND IN YOUR WORK.

32. This course consists of eight plates, five on the solution of **geometrical problems,** two on **projection** (pro-jec'tion), and one on **intersections** (in-ter-sec'tions) **and developments** (de-vel'op-ments).

The first five plates are to be drawn from the instructions in this Paper, and no copies will be sent to the student for reference, except a copy of the first plate, which is annexed to this Instruction Paper.

Copies of the remaining plates will be sent to you as you need them. As soon as you have finished your drawing of Plate I., send it to us at once in the mailing tube which we sent to you. Do not wait until you have several plates finished before you send them to us, but mail each one as you finish it.

After you have sent Plate I. to us, read the instructions for drawing Plate II. and begin to work on that plate. Our instructors have in the meantime corrected your first plate and have returned it to you. The corrections made by them on the drawing or on a separate sheet of paper should be carefully noted by you, and should guide you in the execution of the remaining plates. Not until the first plate has been returned to you should you send the second plate to us, for we are desirous of having the mistakes on the first plate corrected on the second and succeeding plates. After you have sent the second plate to us for corrections begin to draw the third plate, but do not send this to us until Plate II. has been returned to you. This method is to be followed until every plate in the course has been drawn and criticised.

Do not fold your drawings or send them to us in anything but a mailing tube such as we furnish to our students. Write your name and address in full with lead pencil on the back of each plate. This will facilitate matters at our schools and will insure the quick return of your work.

Do your work neatly and keep your drawings clean. Trim them carefully and avoid the punching of holes into them with compasses or dividers. Work slowly and study the principles involved in each new plate. Should you have any difficulties at any stage of the course, write to us at once and our instructors will clear them away. Do not feel discouraged if your drawing is not as good as the copy we send you, or if it is returned to you with a large number of corrections. We do not expect perfect drawings from you at the beginning, and in pointing out your faults we are simply doing our duty, namely, to guide you in the right direction, which leads to a complete understanding of the subject and a knowledge of how to make geometrical and mechanical drawings.

GENERAL DIRECTIONS FOR DRAWING THE PLATES.

33. Next to knowing how to use the instruments and how to letter correctly, is a knowledge of how to properly locate the various views of a drawing on the sheet of paper. The views should be so located on the paper that there is no crowding of the parts. Every drawing has a **cutting edge,** which is far enough away from the outside edge of the sheet of paper to allow for the cutting out of the thumbtack holes, and the student may use this margin for testing the flow of ink in his pen and the width of his lines. The size of the drawings in this course, after they have been trimmed along the cutting edge, is $14\frac{1}{2}'' \times 18''$. The **working edges** (sometimes called border lines) within which the drawing is made are drawn $\frac{1}{2}''$ from each cutting edge, giving a space of $13\frac{1}{2}'' \times 17''$. On every drawing the cutting edges and border lines should be drawn first and the drawing then be spaced inside of the latter. In trimming your plates take care not to cut on either side of the cutting edges.

The first five plates in this course will deal with practical geometrical problems, and the student will be required to draw these from the descriptions and illustrations given in the following pages. A copy of the first plate will be found in

this Instruction Paper. The student should follow the explanations closely and learn the principles involved in the construction of each problem, so as to be able to apply them whenever he meets with a similar problem in his practice. In fact, the object of each plate in the course is twofold—namely, to teach the student how to draw, and, secondly, to teach him a new principle whenever he draws a new figure. The work should be done accurately and neatly, and be sure, therefore, that you do not begin to draw until you have washed your hands. All the work should be penciled in before you do any inking, and all curves should be inked before the straight lines; for it is easier to join a straight line to a curve than it is to have a curve join a straight line without causing an ugly place at the joint. As stated in **Art. 22,** the student should do his lettering with great care. The drawing should not be lettered until all lines and curves have been inked in. You must not attempt to do the lettering without drawing guide lines with **T** square and triangles. No letters are to be put on the geometrical figures such as are shown in the following pages. They are placed there for descriptive purposes only. The student should print the number and title of each problem above the construction, as shown on the sample plate inserted in this Paper. All construction lines should be drawn lightly, so that they can be erased easily. Too much rubbing on a drawing not alone spoils the general appearance, but causes rough spots on the paper, on which dust will accumulate and adhere.

DIRECTIONS FOR DRAWING PLATES I. TO V. INCLUSIVE.

34. After you have carefully read the preceding articles and have practised the lettering and the use of the instruments, you begin to draw Plate I. A sample of this plate, on a reduced scale, is inserted in this Paper, and shows the general arrangement of the problems and the method of dividing the sheet of paper. This plate should be referred

to frequently, but the dimensions should be taken from the text, as the sample plate is not drawn full-size and gives no dimensions. In no case should a drawing be measured by student or workman; they should always be guided by the dimensions which are written on the drawing. For while the drawing itself may not be made exactly according to size, the dimensions are generally given in numbers which can be depended upon.

Fasten your paper, which measures about $15'' \times 20''$, to the drawing-board, as explained in **Article 16,** and proceed to draw your cutting and working edges according to the sizes given in the last article. No part of the drawing proper should be placed between the cutting and working edges.

Draw a light horizontal line midway between the two working edges, and then draw two vertical lines which will divide the space between the two vertical working edges into three equal spaces. This subdivision will give six spaces of $6\frac{3}{4}'' \times$ about $5\frac{5}{8}''$ each, within which six problems are to be drawn. The lines are to be drawn very lightly, as they are not to be inked and must be erased. They are shown as dotted lines in the sample plate. Above each problem the number and title should be printed, as shown in the sample plate. The exact wording of the title is printed in the text above the description of each problem. The first line of lettering should begin $\frac{1}{2}$ inch below the top line of each space. The capitals are $\frac{3}{32}$ inch high, and the space between two lines of lettering is $\frac{1}{8}$ inch. The highest point of the drawing should not be nearer than $\frac{1}{2}$ inch below the lowest line of lettering, so that if there is one line of lettering only, the space between the top line of the space and the highest point of the drawing would be $\frac{1}{2}'' + \frac{3}{32}'' + \frac{1}{2}'' = 1\frac{3}{32}''$. If there are two lines of lettering this space becomes $\frac{1}{2}'' + \frac{3}{32}'' + \frac{3}{32}'' + \frac{3}{32}'' + \frac{1}{2}'' = 1\frac{9}{32}''$. It is therefore necessary to determine by judgment whether the lettering will occupy one or two lines, before the problem can be drawn. The latter should be placed centrally between the lowest line of lettering and the lower border line of the space. The letter-

ing should not be put in until all the problems on that plate have been drawn and inked in.

Centrally between the upper cutting and working edges print the title of the drawing, which will be "Geometrical Drawing, Plate I.," for the first plate; "Geometrical Drawing, Plate II.," for the second, etc. These letters are all capitals, $\frac{3}{32}$ inch high. In the right-hand corner, between the lower cutting and working edges, print your name, class letter and number, and in the left-hand corner the date. The sample page will show the manner of printing these.

35. The student should make his drawing neatly and accurately. All dimensions should be closely followed and the lines be made exactly of the required lengths. If a line is to be drawn through two points, be sure that it does not pass alongside of either of them; and if two lines are to meet at a point, take care not to have them cross each other, but have the point sharp and decisive. In drawing a line tangent to an arc, do not let the line cut the arc, but have it touch only at one point.

In the first five plates, which consist of construction problems, a distinction has to be made between three kinds of lines, namely, the **given lines,** the **construction lines,** and the **required lines.** The given lines are made full and of ordinary width, that is, of a width shown in Fig. 25, line *ab*. The construction lines are dotted and of the same width as the given lines. The required lines are full and a trifle heavier than the given lines, as shown by line *ce*, Fig. 25.

The student must ink in the curved lines before the straight lines, the dotted lines before the full ones, and the fine lines before the heavy ones. The working edges are made as heavy as the required lines.

After you have your pen adjusted for drawing lines of a certain width, draw **all** these lines before the pen is reset for another set of lines of a different width. Try your pen on the waste edges of your paper before you draw the lines.

In actual working drawings the construction lines are

always erased, unless some difficult construction requires the lines to remain there for the guidance of the workman. In these problems, however, these lines are inked in dotted and should be made with great care, the dots being about $\frac{1}{16}$ of an inch long.

The division lines of the sheet and any unnecessary lines should be carefully erased before any inking is done, and if it is found necessary to use the rubber after the drawing has been inked, care should be taken not to erase any ink lines. If the latter does occur, you should go over that line with your pen, being sure to make it the required width.

In using your compasses be sure you have a sharp needle-point. Bear lightly on your compasses or dividers, so as not to make large holes in the paper.

Again, do your lettering with great care and observe the construction of each letter. Do not hurry your work, but be satisfied with slow advancement at the beginning, and you will find that the careful worker will reap the greatest benefits from his studies and will have no difficulty in drawing the plates in the latter part of this course.

After you have completed your drawing, cut it off along the cutting edges, but do not use your **T** square as a guiding edge for your knife. Cut accurately along the lines, and use a sharp knife or a pair of scissors.

Write your name and address on the back of the plate with pencil, put it into one of the mailing tubes which we sent you, and mail it to us.

Then begin your work on Plate II., observing the above rules, but do not send this to us until you have received Plate I. back from us and have obtained a passing mark. Read and profit by the suggestions made by the instructor on your first plate while drawing Plate II.

GEOMETRICAL PROBLEMS. PLATE I.

(The student should refer to the sample plate.)

36. Problem 1. *To bisect* (bi-sect′) *a straight line or an arc.*

Let *ab*, Fig. 24, be the given line or arc, the line being 4″ long. From *a* as a center, with a radius greater than half of *ab*, describe arcs *c* and *d*. From *b* as center, with the same radius, describe arcs cutting the former in *c* and *d*. Through these points of intersection draw the line *cd*, which will divide the line and arc *ab* into two equal parts.

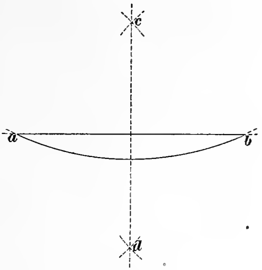


Fig. 24.

Problem 2. *To draw a perpendicular to a straight line when the point is at or near the end of the line.*

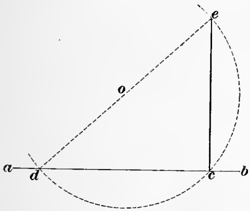


Fig. 25.

Let *ab*, Fig. 25, be the given line, which is to be drawn 4″ long. Let *c* be the point at which the perpendicular is to be drawn, and let it be $\frac{1}{2}$″ from *b*. Take any point *o* above the line *ab* as a center, and with the distance *oc* as a radius describe the arc *ecd* cutting *ab* in *d* and *c*. Draw the line *od* and produce it until it cuts the arc at *e*. Join *e* and *c* by a line, and *ec* will be the perpendicular required.

Problem 3. *To draw a perpendicular to a straight line from a point without it.*

Let *ab*, Fig. 26, be the given line, 4″ long, and *d* the given point. From any point *c* in the line *ab*, about $\frac{1}{2}$″ from *b*, as a center, and with a radius *cd*, describe the arc *de* cutting *ab* in *f*. With *f* as a center and the radius *fd*, describe arcs cutting the first arc at *d* and *e*. Through the points *d* and *e* draw the line *de*, which will be the perpendicular required.

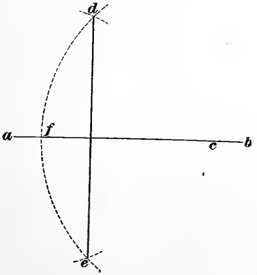


Fig. 26.

Problem 4. *To draw a straight line parallel to a given straight line.*

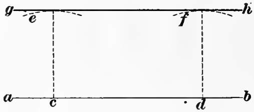


FIG. 27.

Let *ab*, Fig. 27, be the given line, 4″ long. From any two points on that line, as *c* and *d*, as centers, and with a radius equal to the given distance between the two lines, which is to be about $1\frac{1}{2}''$, describe the arcs *e* and *f*. Draw the line *gh* tangent to the arcs *e* and *f*. The straight line *gh* is parallel to *ab* and a given distance from it.

Problem 5. *To bisect a given angle.*

Let *aob*, Fig. 28, be the given angle. With the vertex *o* as a center, and any radius, describe an arc cutting the sides of the angle at *c* and *d*. From *c* and *d* as centers, with the same or any radius, describe arcs cutting each other at *e*. Through this point of intersection draw the line *oe*, which bisects the given angle.

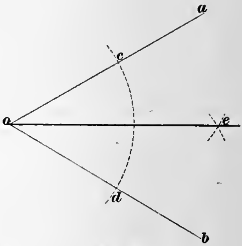


FIG. 28.

Problem 6. *To bisect the inclination* (in-cli-na′tion) *of two straight lines, the vertex* (ver′tex) *of which is inaccessible* (in-ac-ces′si-ble).

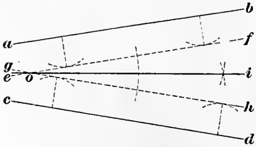


FIG 29.

Let *ab* and *cd*, Fig. 29, be the given lines, $3\frac{1}{2}''$ long. Draw *ef* and *gh*, respectively, parallel to *ab* and *cd*, by the method given in Problem 4, *ef* being the same distance from *ab* as *gh* is from *cd*, and intersecting each other at *o*. Bisect the angle *foh* by the method given in Problem 5, and the line *oi*, which bisects this angle, also bisects the inclination between the given lines.

GEOMETRICAL PROBLEMS. PLATE II.

37. The cutting, working, and division lines are laid out the same as for Plate I., and the student should carefully reread the instructions contained in Articles 34 and 35 and profit by the criticisms the instructor has made on Plate I. Do not send this plate to the Schools until Plate I. has been returned to you.

Problem 7. *To divide a straight line into a required number of equal parts.* Let *ab*, Fig. 30, be the given straight line, $3\frac{3}{4}''$ long, to be divided into eight equal parts. From *a* draw an indefinite straight line, *ac*, forming an angle with *ab*. Set off on the line *ac* eight equal parts of any length. Join the points 8 and *b* by a straight line, and draw lines parallel to it through the points 1, 2, 3, 4, 5, 6, 7, and they will divide *ab* into the required number of parts, *a* 1′, 1′ 2′, etc., all being equal to each other, and each equal to one-eighth of the distance *ab*.

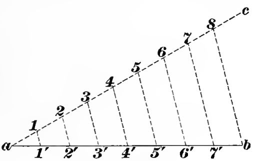


Fig. 30.

Problem 8. *To draw a straight line to form any required angle with another straight line from a given point in it.*

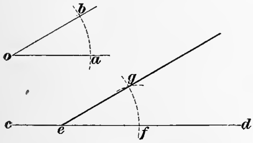


Fig. 31.

Let *cd*, Fig. 31, be the given line, 4″ long, *e* the given point, and *aob* the given angle.

From *o* as center, with any convenient radius, describe an arc *ba*. From *e* as center, and with the same radius, describe the arc *gf*. From *f* as center, with a radius equal to the chord of the arc *ba*, describe an arc intersecting *gf* in *g*. Through the points *g* and *e* draw the straight line *eg*, which is the required line to make the angle $gef = boa$.

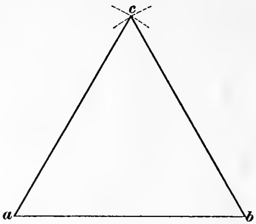


FIG. 32.

Problem 9. *To construct an equilateral triangle, one side being given.*

Let *ab*, Fig. 32, be the given side, $3\frac{1}{2}''$ long. From *a* and *b* as centers, with a radius equal to *ab*, describe arcs cutting each other in *c*. Draw the lines *ac* and *bc*. The triangle *abc* is equilateral, that is, $ab = ac = bc$.

Problem 10. *To construct an equilateral triangle, the altitude being given.*

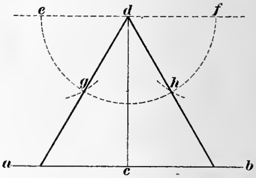


FIG. 33.

Let *cd*, Fig. 33, be the given altitude, equal to $3''$. Through the point *d* draw a straight line, *ef*, perpendicular to *cd*, by the method shown in Problem 2. Through the point *c* draw another straight line, *ab*, parallel to *ef*, by the method shown in Problem 4. From *d* as a center, and any convenient radius, describe a semicircle cutting *ef* in *e* and *f*. From *e* and *f* as centers, with the same radius, intersect the semicircle in *g* and *h*. From *d* and through the points *g* and *h* draw the lines *dg* and *dh*, and extend them until they meet the line *ab*.

Problem 11. *To construct a triangle, two sides and the included angle being given.*

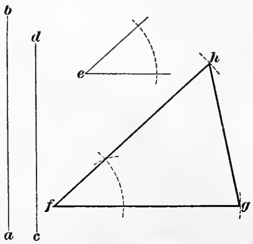


FIG. 34.

Let *ab* and *cd*, Fig. 34, be the two given sides, $3\frac{1}{2}''$ and $3''$ long respectively, and *e* the given angle, about 60°.

Draw the line *fg* equal to *ab*. At the point *f* construct an angle equal to *e*, by the method given in Problem 8, and make *fh* equal to *cd*. Join the points *h* and *g*, and *fgh* is the triangle required.

Problem 12. *To construct a parallelogram, the length of the sides and one of the angles being given.*

Let *ab* and *cd*, Fig. 35, be the lengths of the two sides, 4″ and $3\frac{1}{2}$″ respectively, and *e* the given angle, about 60°. Draw *gf* equal in length to *ab*. From *f* draw *fh*, equal in length to *cd*, and forming with *gf* an angle equal to the given angle *e*. From the point *g* as a center, with a radius equal to *cd*, and from *h* with a radius equal to *ab*, describe arcs intersecting at *i*. Draw *hi* and *gi*, and *gfhi* is the parallelogram required.

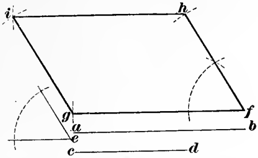


FIG. 35.

NOTE.—Do not mail this plate to us until Plate I. has been returned to you.

GEOMETRICAL PROBLEMS. PLATE III.

38. The directions for dividing the sheet of paper given for Plates I. and II. also apply to this plate, as well as to Plates IV. and V.

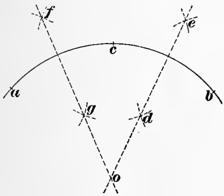


FIG. 36.

Problem 13. *Given an arc of a circle, to find the center.*

Let *ab*, Fig. 36, be the given arc. Take any three points on the arc, as *a*, *c*, *b*. Bisect the distances *ac* and *cb* by the lines *fg* and *ed*, and the intersection of these lines at *o* will be the center of the circle of which the given arc is a part.

Problem 14. *In a given circle to inscribe a square.*

Let *abcd*, Fig. 37, be the given circle, 4″ in diameter. Draw two diameters, *ac* and *bd*, at right angles to each other, by the method shown in Problem 1. Join the points *a*, *b*, *c*, *d*, where the diameters intersect the circumference, and these lines will be the sides of the square.

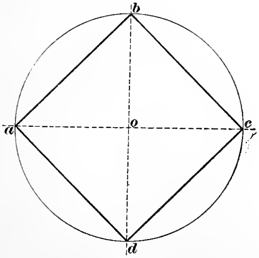


FIG. 37.

Problem 15. *In a given circle to inscribe a regular hexagon* (hex'a-gon).

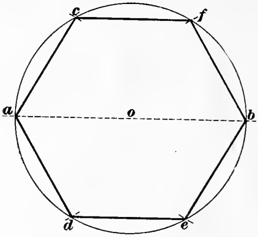


FIG. 38.

In Fig. 38, let *o* be the center of the given circle, 4″ in diameter. Draw the diameter *ab*. From the points *a* and *b* as centers, and a radius equal to *ao* or *ob*, the radius of the given circle, describe arcs cutting the circumference of the circle in the points *c, d, e, f*. Join the points *a, c, f, b, e,* and *d*, and *acfbed* will be the required hexagon.

Problem 16. *In a given circle to inscribe a regular pentagon* (pent'a-gon).

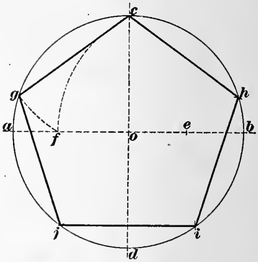


FIG. 39.

Let *abcd*, Fig. 39, be the given circle, 4″ in diameter. Draw the diameters *ab* and *cd* at right angles to each other, and bisect *ob* in the point *e*. From the point *e* as center, and with a radius equal to *ec*, describe an arc cutting *ab* in *f*. From the point *c* as center, and with a radius *cf*, describe an arc cutting the circumference of the circle in *g*. Join the points *c* and *g*. Then draw the chords *ch, hi, ij, jg*, each equal to *gc*, and *gchij* is the pentagon required.

Problem 17. *In a given circle to inscribe a regular heptagon* (hept'a-gon).

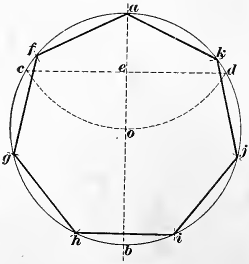


FIG. 40.

Let *o*, Fig. 40, be the centre of the given circle, which is 4″ in diameter. From any point on the circumference of the circle, as *a*, as a center, and with a radius *ao*, equal to the radius of the circle, describe an arc, *cod*, cutting the circumference in *c* and *d*. Draw the chord *cd*, and join *ao*, which bisects *cd* in the point *e*. Set off from *a* a distance equal to *ce* or

de, around the circle, and by joining the points the heptagon *akjihgf* will be completed.

Problem 18. *In a given circle to inscribe a regular polygon* (pol'y-gon) *of any number of sides.*

In Fig. 41 describe a circle with a diameter of $3\frac{1}{2}''$, and draw the diameter *b*9. Divide this into as many equal parts as the proposed polygon has sides (in this case nine). Bisect *b*9 in *o*, and draw $o3''$ perpendicular to *b*9, making $4'3''$, the part without the circle, equal to three-fourths of the radius *bo* or $o4'$. From the point $3''$ draw the straight line $3''a$ through the second division from *b* on the diameter *b*9, producing it to meet the circumference in *a*. Join *a* and *b*, and *ab* will be one side of the required polygon. The others may be stepped off around the circumference.

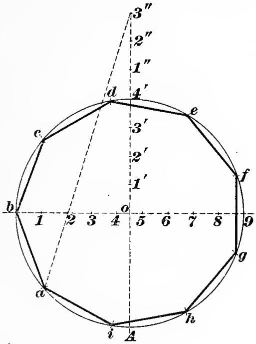


FIG. 41.

GEOMETRICAL PROBLEMS. PLATE IV.

39. The preliminary directions for this plate are the same as for the preceding ones, and the student should profit by the criticisms made by the instructors on those plates.

Problem 19. *Given one side of a regular polygon, to construct the polygon.*

Let *ab*, Fig. 42, be the given side, $3\frac{1}{2}''$ long. Produce *ab* to *c*, making *bc* equal to *ab*. From *b* as a center, with a radius *ab*, describe a semicircle. Divide this into as many equal parts as there are sides in the proposed polygon (in this case five). From the point *b*, and through the second division from *c*, draw the straight line *b*3. Bisect the lines *ab* and *b*3 by perpendiculars intersecting in *o*. From *o* as a

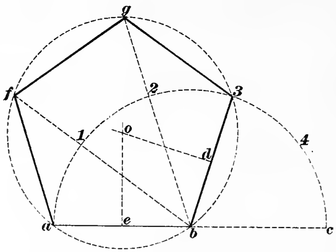


FIG. 42.

center, with a radius *oa*, *ob*, or *o*3, describe a circle. From *b*, and through the remaining divisions in the semi-circle *a*3*c*, draw lines till they meet the circumference in *f* and *g*. Join the points 3*g*, *gf*, and *fa*, and *ab*3*gf* is the polygon required.

Problem 20. *To draw a tangent to an arc or circle at a given point.*

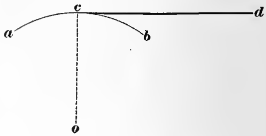


FIG. 43.

Let *acb*, Fig. 43, be the arc, and *c* the given point. From *c* to the center *o* draw the radius *co*. Through *c*, perpendicular to *co*, draw the line *cd*, which is the required tangent.

Problem 21. *To draw a line tangent to two arcs, and to find the points of tangency* (tan′gen-cy).

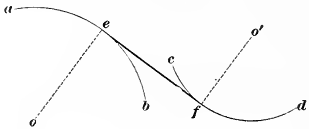


FIG. 44.

Let *ab* and *cd*, Fig. 44, be the given arcs. Draw the line *ef* tangent to both arcs. From the centers *o*′ and *o* draw perpendiculars to *ef*. The points *e* and *f*, where these lines meet the line *ef*, are the points of tangency between *ef* and the two arcs.

Problem 22. *To find the point of contact of two tangent arcs or circles.*

Let *ab* and *cd*, Fig. 45, be the two arcs tangent to each other. Join their centers *o* and *o*′; and the point *e*, where the line *oo*′ cuts the arcs, is the point of contact required.

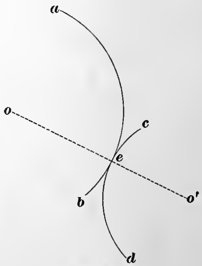


FIG. 45.

Problem 23. *To draw a straight line equal in length to any given arc.*

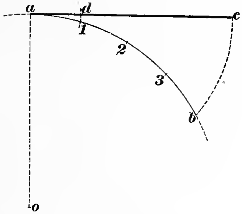


FIG. 46.

Let *ab*, Fig. 46, be the given arc. Draw a straight line connecting the center of the arc, *o*, with its one extremity, *a*. Draw *ac* perpendicular to *oa*, and divide the arc into four equal parts. With *a* as a center, and a radius equal to the chord of *a*1, describe an arc cutting *ac* in *d*. With *d* as a center, and *db* as a radius, describe an arc cutting *ac* in *c*. Then *ac* is the required length.

Problem 24. *To find the arc of a circle with a given radius, which shall be equal in length to a given straight line.*

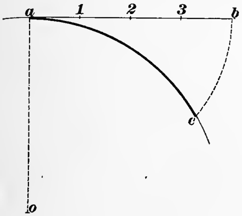


FIG. 47.

Let *ab*, Fig. 47, be the given line. At its one extremity, *a*, erect a perpendicular, *ao*, and make it equal in length to the given radius. With *o* as a center, and a radius equal to *ao*, describe an arc. Divide the straight line *ab* into four equal parts, and with the first division, marked 1, as a center, and 1*b* as a radius, describe an arc cutting *ac* in *c*. Then *ac* is nearly equal in length to *ab*.

NOTE: Problems 23 and 24 are only approximately correct, and should only be depended upon when the arc is less than about one-sixth of the circumference of the circle. For larger arcs numerical calculations would give the most satisfactory results.

GEOMETRICAL PROBLEMS. PLATE V.

40. There are four problems on this plate, instead of six, the last two problems requiring two vertical spaces each for their construction. Therefore the student should divide the sheet of paper into three equal parts vertically, and the first of these should be divided into two equal spaces by a horizontal line.

Problem 25.—*To describe an ellipse* (el-lipse′), *the two diameters being given.*

In Fig. 48, draw the two given diameters, ab $3\frac{1}{2}''$ long and cd $2\frac{1}{4}''$ long, at right angles to each other, intersecting at their point of bisection o. From o as a center, with oa or ab as radius, describe a circle; and from the same point as center, with oc or od as radius, describe another circle. Divide both circles into the same number of equal parts, 1, 2, 3, 4, etc., and 1′, 2′, 3′, c, etc. This is best done by dividing the upper half of the larger circle into the required number of parts, and then drawing radial lines from these divisions through the center, dividing the lower half of the larger circle and the entire smaller circle into the same number of parts. From the points of division of the larger circle draw lines perpendicular to ab, as $1e$, $2f$, $3g$, etc., and from the corresponding divisions of the smaller circle draw lines parallel to ab, as $e1'$, $f2'$, $g3'$, etc., cutting the perpendicular lines in the points e, f, g, etc. Through the points of intersection of these lines draw the circumference of the required ellipse. It is advisable for the student to first sketch the ellipse, through the points found, with a pencil before he applies his irregular curve. This latter should be used as was explained in Art. 21.

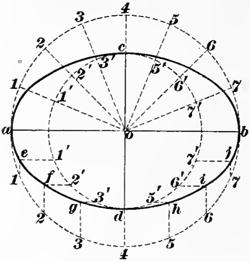


FIG. 48.

Problem 26. *Given the diameters, to describe an ellipse by circular arcs.*

Let ab and cd, Fig. 49, be the given diameters, ab being $3\frac{1}{2}''$ long and cd $2\frac{1}{4}''$, at right angles to and bisecting each other at o.

From c on cd, at a distance less than co, lay off a distance cf. From a on ab lay off the distance $ae = cf$. Join e and f by a straight line. Bisect the line ef by hg, which will be perpendicular to ef and cut cd

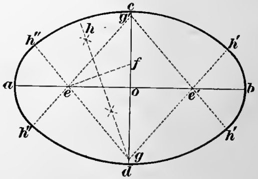


FIG. 49.

in g. Through the points g and e draw a straight line geh''. Make $og' = og$ and draw the line $g'eh''$. Also make $oe' = oe$, and draw the lines gh' and $g'h'$. From g and g' as centers, and a radius equal to gc or $g'd$, describe the arcs $h''ch'$ and $h''dh'$, respectively. From e and e' as centers, and ae or $e'b$ as radius, describe the arcs $h''ah''$ and $h'bh'$, respectively. Then $acbd$ is the required ellipse.

Problem 27. *Given the diameter and pitch, to draw a helix* (he'lix).

Definition. The **helix** is a curve formed by a point traveling around a cylinder, and, while thus moving, advancing a certain uniform distance along the length of the cylinder. The winding curve shown in Fig. 50 is thus produced, making one complete revolution around the cylinder in the space $c12$, which is called the **pitch** of the helix. The line $a9'$ is called the **axis,** and is also the axis of the cylinder around which the helix is described. The perpendicular distances from the axis to any point of the helix are all equal to the radius of the cylinder.

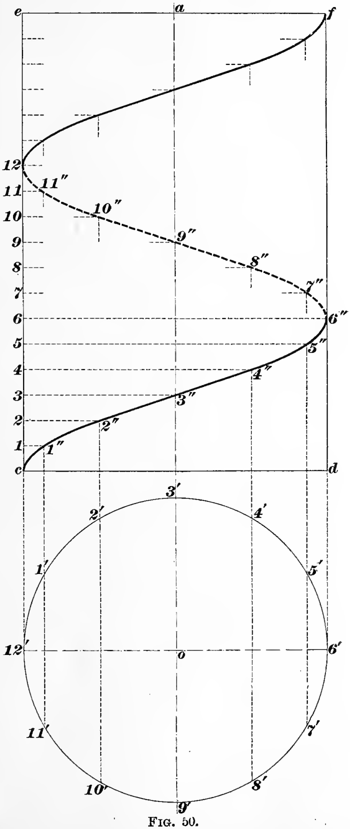


Fig. 50.

Construction of the helix. Let $cdef$, Fig. 50, rep-

resent the side view of a cylinder on which the helix is situated, and let its diameter be 4″; *ao* is the axis and *c*12 is the pitch = $2\frac{1}{2}''$. One and a half turns of the helix are to be drawn, making the length of the cylinder, *ce* or *df*, = $3\frac{3}{4}''$. Draw the line *ef* 4″ long, 3″ from the top border line, and make *ec* and *fd* perpendicular to it and $3\frac{3}{4}''$ long. After you have completed the side view of the cylinder, namely, the rectangle *cefd*, you draw the bottom view of the cylinder, which is the circle below, with the center *o*. This center is located $2\frac{1}{2}''$ below the line *cd*, and the circle is 4″ in diameter.

Draw the axis *ao* and the diameter 12′*o*6′. Divide the circle into any number of equal parts (12 in this case) beginning at 12′, the one extremity of the diameter 12′*o*6′. We may remark that the greater the number of these divisions, the greater will be the accuracy of the curve.

Set off, on *ce*, the pitch of the helix, namely, *c*12, equal to $2\frac{1}{2}''$, and divide it into the same number of equal parts as the circle (12 in this case), marked 1, 2, 3, 4, 5, 6, etc., in the figure.

Then through the points of division of the circle draw straight lines perpendicular to *cd* or parallel to the axis *ao*, and through the points of division of the pitch draw straight lines parallel to *cd* or perpendicular to the axis *ao*. The points of intersection of the corresponding pairs of these two sets of lines will be points in the required curve, as 1″, 2″, 3″, 4″, 5″, etc., through which the curve should be drawn with an irregular curve. The part of the helix from 6″ to 12 is dotted because it is located on the back half of the cylinder and cannot be seen by looking at the front of the cylinder. Anything which is hidden is represented by dotted lines in mechanical drawings.

Problem 28.—*To draw the Ionic* (i-on′ic) *volute* (vo-lute′), *the height being given.*

This problem occupies the last two vertical spaces on this plate, and consists of the upper figure, which is the volute proper, and the lower figure, which shows the enlarged construction within the eye of the volute, which is the circular termination at the center.

Divide the space on your paper into two equal parts by drawing the vertical line *de* (Fig. 51), which will also cut the lower figure in *a* and *d*. 2″ to the right of this, and 4″ below

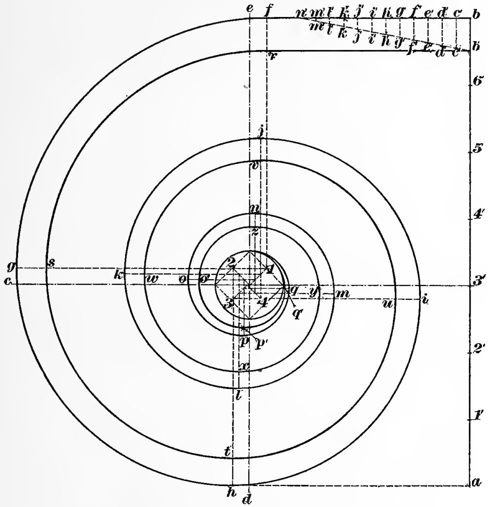


FIG. 51.

the top border line, draw the vertical line *ab*, which is the height of the volute and is 4″ long. Divide this line into seven equal parts, as *a* 1′, 1′ 2′, etc., and through the third division, from the bottom, draw the horizontal line 3′*c*. From the point of intersection of this line and the line *ed* as a center, and with a radius equal to one-half of one of the equal divisions on *ab*, describe a circle, which forms the eye of the volute.

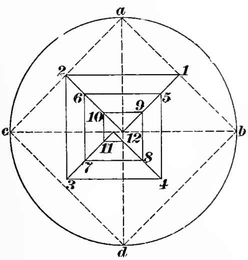


FIG. 51*a*.

For finding the centers for the twelve quadrants of the volute a constructionis employed which is shownenlargedinFig. 51*a*.

On the line *ad*, which is a prolongation of the line *de*, and $3\frac{3}{4}''$ below the center of the eye of the volute, we take another center and describe a circle having a diameter of $2''$. Within this we make the following construction:

Draw the horizontal diameter *cb* perpendicular to *ad* at its middle point, and join *c*, *a*, *b*, and *d* by straight lines. From 1, the middle point of *ab*, to 2, the middle point of *ac*, draw the horizontal line 1, 2. Divide the distance between the lines *cb* and 1, 2 into 3 equal parts, and lay off $2\frac{1}{2}$ of these parts below the line *cb*, and draw the line 3, 4, the points 2 and 3 being joined by a perpendicular line. Then, with your 45° triangle, draw lines from 1 and 2 toward the center, and also from 3, which meets the line *cb* $\frac{1}{2}$ space to the left of the center. From this point of intersection draw another line at 45°, meeting the line 3, 4 at 4. Then draw the vertical and horizontal lines as shown, all terminating at the 45° lines. The points thus obtained are marked 1, 2, 3, etc., up to 12. These will be twelve centers for the twelve quadrants, which will give three complete turns to the volute.

After the student thoroughly understands this construction, he should insert a similar one into the eye of the volute. Then draw the horizontal line *bf* (Fig. 51), and, with 1 as a center and a radius equal to $1f$, describe the quadrant *fg*. With 2 as center, and a radius $2g$, draw the quadrant *gh*. With 3 as center, and a radius $3g$, draw the quadrant *hi*. With 4 as a center, and a radius $4i$, draw the quadrant *ij*, and continue this operation with every center, the last being 12, when a radius of $12q$ describes the quadrant from *q* until it becomes tangent to the eye.

This completes the drawing of the outer volute, and it now remains to draw the inner one. For this purpose lay off $bb' = \frac{3}{8}''$. From b' draw a line meeting *bf* in any point, such as n', a convenient distance being $1\frac{1}{2}''$. Divide bn' or $b'n'$ into 12 equal parts and join the corresponding divisions by vertical lines as shown, giving the distances bb', $c'c'$, $d'd'$, $e'e'$, $f'f'$, etc., up to $m'm'$. Then draw the horizontal line $b'r$ intersecting the line $f1$ in *r*, the distance *fr* being equal to bb'. Lay off a distance equal to $c'c'$ on the line $g2$, giving the point *s*. Lay off $d'd'$ on the line $3h$, giving the point *t*;

lay off $e'e'$ on $4i$, giving the point u; lay off $f'f'$ on $5j$, giving the point v, and continue this until $m'm'$ is laid off on $12q$, giving q^1. In order, then, that the last quadrant will be tangent to the eye, and the first quadrant being a distance equal to bb' from the former volute, the centers must necessarily be shifted. This is accomplished as follows: The point r has been obtained. The first quadrant has to pass through the two points r and s Therefore, with a radius equal to $1r$, the compasses are moved along 1, 2 until the new $1r$ is equal to the new $1s$, which center will be found to be a trifle to the left of the first center marked 1. The next quadrant has to pass through the points s and t. Hence the center will be found a trifle below the old center 2 on the line $2h$, the radius being $2s$. The next center is a trifle to the right of 3 on the line $3i$, and the radius is $3t$. This operation is continued until the inner volute is completed. The student should be sure to have the quadrants meet each other without forming ugly corners or overlapping each other; the construction should be made with great care.

PRACTICAL HINTS ON THE USE OF INSTRUMENTS.

41. The instruments and their principal uses have been fully discussed in the opening chapter of this Paper, and by a correct application of the rules laid down therein, and a careful study of the geometrical problems just drawn, the student should be able to make drawings as neatly and accurately as an experienced draughtsman. However, there is no profession which does not pride itself on the number of "kinks" or "practical hints" which have been acquired by years of experience and practice. And so the draughtsman and architect have discovered many "short cuts" for the execution of some particular problem, or some novel and helpful ways of using the instruments at their disposal.

We would not be fulfilling our mission if we should omit reference to some of these thoroughly practical uses of the instruments, and while the student will acquire a number of

them himself by close observation and his own ingenuity, the following hints may be of service to him in his work.

42. The student must have observed, while constructing the geometrical problems, that the only instruments used, with but few exceptions, were the **T** square and compasses. The scale was, of course, used for measuring the lengths of the given lines, and the triangle for the drawing of vertical lines in the last few problems; but it must have occurred to all, that most of the methods described could be used when nothing is at hand but a straight-edge, a pair of compasses, and a pencil. However, compasses are not always at one's disposal when the **T** square, triangles, scale, and pencil are. The following constructions will be helpful in these cases, and are simpler and therefore more rapid than the constructions just drawn. However, we wish to impress this fact firmly on the mind of each student: that the principles underlying the construction of the geometrical problems are very essential to the education of every craftsman, as all constructions, of whatever nature, are based on geometrical principles.

43. *To divide the distance between two lines into any number of equal parts.*

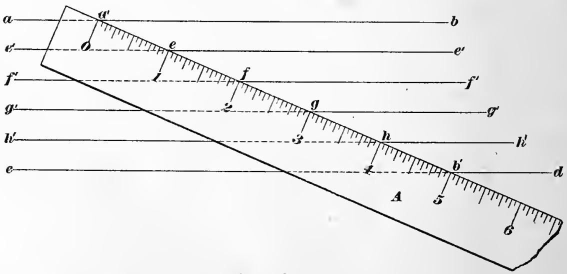


Fig. 52.

Let *ab* and *cd*, Fig. 52, be the given lines, and let it be required to divide the distance between them into five equal

parts. Lay your scale, A, diagonally across the distance, as shown in the figure, so that the diagonal distance embraces an equal number of divisions, as five inches or five one-half inches $= 2\frac{1}{2}''$. Then mark off the points e, f, g, h on the even inch marks, a' and b' being on the lines ab and cd. Through the points e, f, g, h draw lines parallel to the given lines, and the distance between them will be divided into five equal parts.

44. *To divide a circle into a given number of equal parts by the use of triangles.*

For inscribing or circumscribing (cir-cum-scri′bing) regular polygons having 4, 6, 8, or 12 sides, the 45° and 60° triangles may be employed as shown in Fig. 53.

For convenience of demonstration the circle has been divided into quadrants. The one marked A shows how the side of an inscribed or circumscribed square may be drawn by using the 45° triangle.

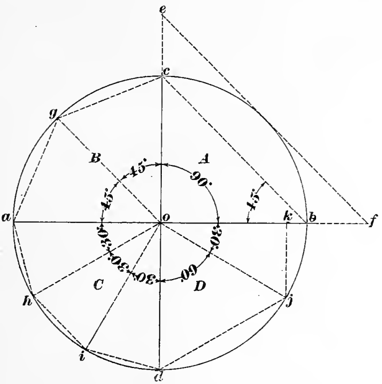


FIG. 53

The inscribed side is limited by the extremities c and b of the diameters; the side of the circumscribed square is tangent to the circle and is limited by the prolongation of the diameters ab and cd at e and f.

Quadrant B is bisected by means of the 45° triangle, and in this way two sides of an octagon, cg and ga, are obtained.

By using the 60° triangle in two different positions we divide quadrant C into three equal parts, or the entire circle into twelve parts.

In quadrant D the 60° triangle is used in one position

only, and we obtain *dj*, one side of a hexagon, and *jk*, one-half of another side. This enables us to inscribe or circumscribe a hexagon.

The student has, therefore, three methods at his disposal for dividing circles—namely, by using (1) the protractor, (2) the geometrical problems, (3) the triangles.

45. *Further use of the triangles.*

As has been pointed out in a previous chapter, triangles are used for drawing lines which have an inclination of 30°, 45°, 60°, and 90° to other lines, and for drawing parallels and perpendiculars to lines having any inclination whatever, as was pointed out in **Arts. 5** and **6.** However, other angles besides those mentioned above may be obtained by means of the 45° and 60° triangles, a knowledge of which may be of service when no protractor is at hand.

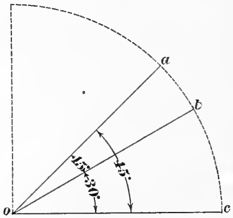


FIG. 54.

If it is desired to obtain an angle of 15°, place your 45° triangle in the position *aoc*, Fig. 54, and draw *oa* and *oc*. Then place your 60° triangle in th position *boc*, the vertex of the 30° angle coinciding with the vertex of 45° angle just drawn, and one side being coincident with the side *oc* of the 45° angle. Draw *ob*, and the angle *aob* will be equal to 45° − 30° = 15°.

For drawing an angle of 75° the triangles are placed in the position shown in Fig. 55. The angle *cob* is equal to 45°; the angle *boa* is equal to 30°, and the total inclination between *oc* and *oa* is equal to 45° + 30° = 75°.

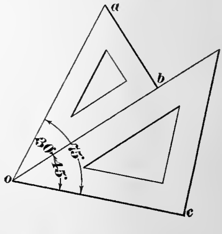


FIG. 55.

For drawing an angle of 105° the triangles *A* and *B*, 45°

and 60° respectively, are placed in the positions shown in Fig. 56, which explains itself, the total angle being $60° + 45° = 105°$.

For reference, we give the following table of angles, which can be easily obtained by using the triangles as shown in the above examples. Angles of 30°, 45°, 60°, 90° can be obtained directly from the use of the 45° and 60° triangles. Angles of 15°, 75°, 105°, etc., are obtained by using the following combinations:

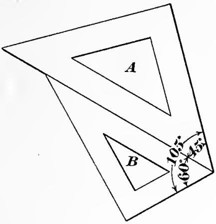


Fig. 56.

$45° - 30° = 15°$	$90° + 45° = 135°$
$45° + 30° = 75°$	$90° + 60° = 150°$
$60° + 45° = 105°$	$90° + 45° + 30° = 165°$
$90° + 30° = 120°$	Straight line $= 180°$

46. *Methods for dividing a circle into any number of equal parts by using protractor or dividers.*

Whenever a circle is to be divided into any number of parts which are factors of 360°, a protractor can be used in the manner explained in **Art. 22.** For example, to divide a circle into five equal parts, make each part equal to $\frac{360°}{5} = 72°$.

However, for dividing a circle into five parts the geometrical method should be used. For dividing a circle into three parts or multiples of three, the 60° triangle is the most convenient to use; for seven parts the geometrical method is used, and for other divisions up to thirteen, which is a safe limit, Problem 18 should be made use of. For dividing a circle, for example, into fifteen parts, it is advisable to first divide it into five parts and then to trisect one of these parts. For obtaining fourteen parts or any other multiple of seven, as forty-nine, divide the circle into seven parts and then subdivide one of these parts with the dividers. This method is more rapid than dividing the entire circle into the required number of parts, and the liability of error is decreased to a minimum.

The student should use his own judgment after these few suggestions as to when and how to use the protractor, the geometrical problems, the triangles, and the dividers for dividing a circle into any number of equal parts, and after a care-

ful study of the various methods he will be enabled to choose the one which is the most expedient in any particular case.

PRINCIPLES OF PROJECTION.

47. Let us take a piece of wire, *ab*, Fig. 57, and hold it up vertically some distance away from a plane surface, as shown in the figure. If we now look down on the wire in the direction indicated by the arrow, we see nothing but a point. If the wire was of an indefinite length it would pierce the plane *defg* in the point *c*. This point is called the projection of the line *ab* on the plane *defg*. In other words, the projection of a point on a plane is the point where a perpendicular from the point to the plane pierces that plane. If we now place the wire into the position *ab*, Fig. 58, all that is necessary to project that line on the plane is to project its two extremities, *a* and *b*, as explained above. The perpendiculars *aa'* and *bb'* pierce the plane in *a'* and *b'*, and joining these by the line *a'b'* we get the projection of the line *ab* on *defg*. And it matters not what the position or shape of the line may be, a line joining the perpendicular projections on the plane will be the projection of the line on that plane.

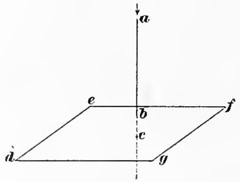


FIG. 57.

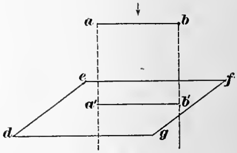


FIG. 58.

In Fig. 59, for example, we have bent the wire *ab* into the circle *acb*, whose axis is perpendicular to the plane *defg*. Projecting several points, as explained above, we find that the perpendiculars pierce the plane in points which, if joined by a line, will form the circle *a'c'b'*. So much for the projection of points and lines.

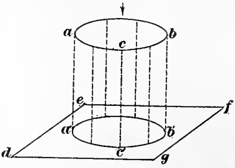


FIG. 59.

Now let it be required to project a surface upon a plane. Let a surface stand in an upright position, as shown in Fig. 60. If we look down upon it, as indicated by the arrow, we simply see a straight line *ab*, and if the surface were prolonged indefinitely it would pierce the plane *efgh* in the straight line *a′b′*. This is called the projection of the surface *abcd* upon the plane *efgh*. It is obtained by projecting the line *ab* upon the plane *efgh*, as previously explained.

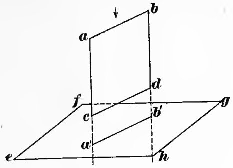


Fig. 60.

If we now place the surface in the position shown in Fig. 61 and project the lines which bound it, we find the projection of *abcd* on *efgh* to be *a′b′c′d′*. The projection of *ab* is *a′b′*; of *bc*, *b′c′*; of *cd*, *c′d′*; and of *ad*, *a′d′*.

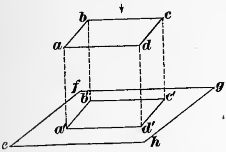


Fig. 61.

Hence we obtain the rule: To project a surface upon a plane, project the lines which bound the surface. It matters not what position the surface occupies or of what shape it is, this rule will always apply.

To show this, we refer the student to Fig. 62, where we have to project the curved surface *abcd* upon the plane *efgh*. Again projecting the lines *ab*, *bd*, *cd*, and *ac*, we obtain the figure *a′b′c′d′*, which is the required projection. If it be required to project a point *m* in the plane *abcd* upon the plane *efgh*, the same rules that have already been given apply. That is, a perpendicular is dropped from the point to the plane, and where that perpendicular pierces that plane is the projection of that point, which in our case is *m′*.

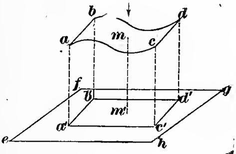


Fig. 62.

Continuing this reasoning, the student will see that the projection of a solid on a plane is the projection of the

surfaces that bound that solid. Hence, to sum up all the principles, we may say:

(1) The projection of a point upon a plane is to find where a perpendicular from the point to the plane pierces the plane.

(2) The projection of a line upon a plane is the projection of the points, which compose that line, upon the plane.

(3) The projection of a surface upon a plane is the projection of the lines, which bound the surface, upon the plane.

(4) The projection of a solid upon a plane is the projection of the surfaces, which bound the solid, upon the plane.

48. A mechanical drawing, intended to guide the mechanic in the construction of objects, should be so made that nothing is left to his imagination and that he can obtain the exact size and shape of each detail from the various dimensions and views. This necessitates each line to be represented in its true length on some part of the drawing, and a sufficient number of views of the object to show its true outlines. That this cannot be accomplished by a perspective drawing can readily be seen by reference to Fig. 63. While a person can get a good general idea, from such a drawing, as to what it is meant to represent, a mechanic could not work from it, on account of the fore-shortening of some of the sides. Besides, perspective drawings of complicated objects are very difficult to make, and become so complicated as to be unintelligible to a workingman.

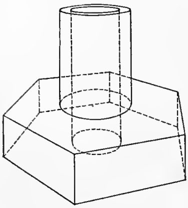


Fig. 63.

We therefore resort to projection, which enables us to overcome the difficulties met with in perspective drawings. By applying the principles of projection presented in the last article we are enabled to make a sufficient number of views of an object to give a person a correct understanding of its shape and size.

The various views of an object are named according to the direction from which the draughtsman was supposed to be looking at the object while drawing that view. The more complex the shape of an object, the more views are required

to represent it on a drawing. We may either look at the top of an object and get the **top view** or **plan.** Looking at the side of an object we get the **side elevation** (el-e-va'tion) or **side view,** and looking at the end the **end view** or **end elevation** is obtained. Sometimes it is advisable, in order to show some detail of construction, to make a section of an object, that is, to image the object cut by a plane along a certain line, and then make a drawing of the part by looking toward the surface which has been cut. According to whether the cut is made along the length or through the width or height of the object, we obtain **longitudinal** (lon-gi-tu'di-nal) and **vertical** or **transverse** (trans-verse') sections.

49. Generally two or three views are sufficient to show the shape or size of an object, namely, the Plan, the Side Elevation, and the End Elevation. For circular or symmetrical figures the latter may be omitted.

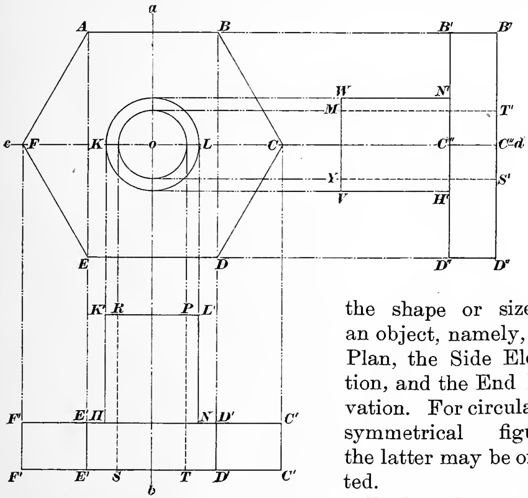


FIG. 64.

To show the arrangement of these views, let us take the object shown in perspective in Fig. 63.

The three views shown in Fig. 64 are the plan, in the upper

left-hand corner, the front elevation below it, and the side elevation to the right of it.

Before the student begins a drawing he has to determine the following: the number of views necessary, how to place the views, and how to space them on the sheet of paper. The various views are connected by center lines, as *ab* and *cd* in the figure, which, as their names indicate, pass through the center of each view and through the center of every circle, where they intersect each other at right angles. These lines are broken lines and consist of dashes and dots.

To draw the object shown in Fig. 64, it is found necessary to draw the plan first, on account of the hexagonal shape of the base. After you have, therefore, decided where to place the center *o*, draw the center lines *ab* and *cd* perpendicular to each other. Around this center *o* construct the hexagon *ABCDEF*, and describe the two circles representing the outside and inside circumferences of the cylindrical extension *KLHN* (shown in the front elevation). This completes the plan of the object, and the next view to draw is either the front or side elevation. Let us draw the front elevation first, which is located below the plan.

First draw the base line $F'C'$ of indefinite length, and project the points F and C on this line by drawing the vertical lines FF' and CC'. Lay off $F'F'$ and $C'C'$ equal to the thickness of the base and draw the upper line $F'C'$. Project the points E and D on the lines $F'C'$ and draw the lines $E'E'$ and $D'D'$. Then draw the line $K'L'$ at the required distance from $F'C'$; project the points K and L on this line, and obtain the points K' and L'. Draw $K'H$ and $L'N$ parallel to the center line *ab*. Project the smaller circle—that is, the hole through the cylinder and base—in a similar manner by projecting the extremities of the horizontal diameter, and draw the dotted lines RS and PT parallel to the center line *ab*. These lines are dotted because they cannot be seen by looking at the object in the direction which gives the front elevation.

To draw the side elevation we proceed as we did for the front elevation, by first drawing the base line $D''B'$, then drawing the upper line $D''B'$ the required distance from it, and joining them by the lines $B'B'$ and $D''D''$; the hollow cylinder

is projected as it was in the front elevation. The lines $B'D''$ will be shorter than the lines $F''C'$ in the front elevation, because the distance between the sides of a hexagon is less than the distance between the corners. The absence of the lines $E'E'$ and $D'D'$ and the presence of the line $C''C''$ in the side elevation, also needs no special mention. Reference to the figure will explain this difference between the two elevations.

After studying the principles of projection and the arrangement of views, as illustrated by the object just drawn, the student should be in a position to represent any object on paper by as many views as are necessary for determining its exact shape and size. He can now begin, after studying the next chapter, on the next series of plates, which consists of a plate on **projection,** one on **projections and conic sections,** each problem representing some new principle, and one plate on **intersections and developments.**

After you have penciled the next plate you should carefully read the articles on inking, shading, dimensioning, and sectioning, which follow the description of the plate, before you attempt to ink in your drawing.

LINES USED ON DRAWINGS.

50. In the preceding articles we have already referred to four kinds of lines which are used on drawings, each having its own particular function to perform. These lines were used for the outlines of the objects, for the representation of hidden parts, for indicating the centers of objects, and for projecting points or lines from one view to another. But a complete working drawing requires, besides those mentioned, lines for the following purposes: shading, which gives the workingman a clearer idea of the shape of the object, and dimensions, which give him the sizes of the various parts.

Our students are to use the following lines, for the purposes indicated, on all drawings in this course, and a correct use of them will avoid any possible complications or errors.

The line *ab*, Fig. 65, is a **light full line** and is used for the outlines of figures. It should not be too light nor too heavy, but the widths shown in the figure should guide the student in drawing any of the lines.

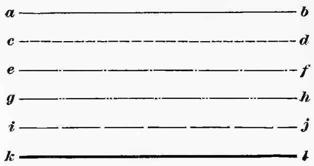


FIG. 65.

The line *cd* is a **dotted line** and is used for the representation of hidden parts on the object, that is, parts which the eye cannot see by looking at the object from the direction which gives the view we are drawing. The dots should all be of the same length and about $\frac{1}{16}$ in. long.

The line *ef* is a **broken line,** consisting of **single dots and dashes.** It is used for center lines of objects, as previously explained. The dashes should be about $\frac{1}{4}$ inch in length, with a dot between them.

The line *gh* is a **broken line,** consisting of **single dashes and two dots** between them. It is used for projection lines, as shown in Fig. 64. The dashes are about $\frac{1}{4}$ inch long, and the distance between two dashes is about $\frac{1}{16}$ inch, in which there are two dots.

The line *ij* is a **broken line** and consists of **dashes.** It is used for dimension lines, and the dashes should be from $\frac{5}{16}$ to $\frac{3}{8}$ inch long.

The line *kl* is a **heavy full line** and is used for shading the outlines of the figures, as will be explained later.

The sizes of the dashes given above can be varied to suit the size of the various parts, making them smaller for very small parts, and even increasing their length for very large drawings.

PLATE VI.—TITLE: PROJECTION.

51. After the student has satisfactorily completed the five plates of geometrical problems and has read the foregoing article on Projection, he can begin to draw Plate VI.,

which illustrates the principles of projection of simple objects. A copy of this plate, on a reduced scale, will be sent to the student, and he is to follow the scales and dimensions marked on the sample plate. The size of the sheet is the same as for the other five plates, and the working edges are the same distance from the cutting edges as before. The space within the working edges, however, is not divided into rectangles, as was done in the previous plates, as the arrangement of figures on a drawing depends upon their size and number, and should be such as to be pleasing to the eye and so as to be easily understood by the workingman. If possible, no part of the drawing should be nearer than $\frac{3}{4}$ inch to the working edges, and the arrangement should be such as to waste as little space on the paper as is consistent with clearness.

Leave sufficient room above the drawing for the title and scale, and print your name and date below the lower working edge, as shown on the sample plate.

After reading the description of each figure, carefully studying the sample plate and understanding the significance of every line, you begin to pencil the drawing. Then, before inking the drawing, read the articles on inking, shading, dimensions, and sectioning, following this article, as the order in which a drawing is finished is an important factor in the rapidity and exactness of its execution.

52. Fig. 1 represents a **rectangular** (rect-an'gu-lar) **prism** $2\frac{5}{8}''$ long, $1\frac{1}{2}''$ wide, and $\frac{3}{4}''$ thick. The front view or elevation, showing the prism standing on one of its small faces, with one of the largest surfaces towards the observer, is drawn first. Draw the horizontal lines *ck* and *am* of indefinite length $2\frac{5}{8}''$ apart, and join them by the lines *ac* and *bd* $1\frac{1}{2}''$ apart. These lines are projected upwards, and the lines *eg* and *fh* are joined by the horizontal lines *ef* and *gh* $\frac{3}{4}''$ inch apart, completing the top view of the prism. To draw the side view, join the lines *ik* and *lm* by the lines *il* and *km*, $\frac{3}{4}''$ apart. The line *il* represents the front face of the prism, and *km* the back.

Fig. 2 represents a **cylinder** $1\frac{1}{2}''$ in diameter and $2''$ long, standing on one of its circular bases. As has been stated

before, every circular or symmetrical object requires for its correct representation center lines which pass through the centers of the drawing and join the various views to each other. These center lines are the first to be drawn, and are marked AB and CD in the figure. From the point O, where these two intersect, as a center, describe a circle having a diameter of $1\frac{1}{2}''$. This will be the top view or plan of the cylinder. To draw the front view of the cylinder, draw the two lines *cg* and *ah* of indefinite length. Join these by the lines *ca* and *db*, $1\frac{1}{2}''$ apart, by projecting the points *i* and *k*. The side view, being the same as the front view, is drawn in a similar manner, *eg* and *fh* being the projections of the lines *cd* and *ab*.

Fig. 3 represents a **hexagonal** (hex-ag′o-nal) **prism** standing on one of its bases. The distance between the opposite corners of the hexagon is $1\frac{1}{2}''$, and the height of the prism is $2''$. Draw the center lines AB and CD, and from the point O, where these intersect, as a center, describe a circle having a diameter of $1\frac{1}{2}''$. Within this circle draw a hexagon whose upper and lower sides are horizontal lines. To draw the front view, draw the two lines *cg* and *ah* of indefinite length, $2''$ apart, and join them by the lines *ca*, *pr*, *ms*, and *db*, by projecting the points *i*, *n*, *j*, *k*. The side view is drawn by first drawing the center line TV and laying off on each side of this the distances *Te* and *Tg*, each equal to BO. Draw the lines *ef* and *gh*, which completes the side view. The student's attention is called to the difference between the front and side views of a hexagonal prism.

Fig. 4 represents a **cone,** $2''$ in height, standing on its circular base, which is $1\frac{1}{2}''$ in diameter. Draw the center lines AB and CD, and, with the point of intersection of these lines as a center, describe a circle $1\frac{1}{2}''$ in diameter. This will be the top view or plan of the cone. To draw the front view, draw the line *ag* of indefinite length, and on that line lay off the points A and C by projecting the points *i* and *k*. $2''$ above the line *ac*, and on the center line AB, locate the point *b*, the vertex of the cone, and draw the lines *ab* and *cb*. The side view is the same as the front view, and is drawn in a similar

manner, the point f being the projection of the point b on the center line FH.

The student will observe that the front views of cylinders and cones are the same as the side views, and in practice the latter are always omitted.

Fig. 5 represents a **pentagonal** (pen-tag′o-nal) **pyramid** standing on its base. The pentagon is inscribed in a circle $1\frac{1}{2}''$ in diameter, and the height of the pyramid is $2''$. Draw the center lines AB and CD, and with the point O, where these intersect, as a center, describe a circle $1\frac{1}{2}''$ in diameter. Within this circle construct a pentagon (by the method shown in Problem 16, Plate III.), the side de being horizontal, and the upper corner g being located on the center line AB. This completes the plan or top view. To draw the front view, draw the base line al of indefinite length, and on it project the points v, d, e, and r. $2''$ above the base, and on the center line AB, locate the point b and draw the lines ba, bs, bt, and bc. To draw the side view, first draw the center line EF, and to the right of it, on the base line, lay off the distance nl equal to go, and, to the left, nh equal to Ox. Lay off nk equal to rp, and project the point b on EF, giving the point i. Draw ih, ik, and il, which completes the side view.

Fig. 6 represents a **wedge,** which is formed by cutting the prism shown in Fig. 1 from c to b. It is drawn similarly to Fig. 1, by first drawing the triangle abc, which is the front view. Its base is $1\frac{1}{2}''$ long and its height is $2\frac{5}{8}''$. The top and side views of the wedge in this position are the same as those of the prism in Fig. 1.

Fig. 7 shows a **hollow cylinder** standing on one of its bases. The outside diameter is $1\frac{1}{2}''$, and the diameters of the three hollow cylindrical portions are $\frac{1}{2}''$, $\frac{7}{8}''$, and $1\frac{1}{8}''$ respectively. Draw the center lines AB and CD, and with the point where these intersect as a center, describe a circle $1\frac{1}{2}''$ in diameter, and one $\frac{1}{2}''$ in diameter representing the smallest hole. Also describe dotted circles $\frac{7}{8}''$ and $1\frac{1}{8}''$ in diameter to represent the other two interior portions of the cylinder which cannot be seen by looking down on it. To

draw the front view, draw the lines *bt* and *aw* of indefinite length, 2″ apart, and join them by the lines *ba* and *dc* by projecting *i* and *k*. As the entire interior portion of the cylinder is hidden from view when looking at the front of it, it will be represented by dotted lines. Draw the horizontal lines *b′d′* and *a′c′* of indefinite length, $\frac{3}{8}$″ from *bd* and *ac* respectively. $\frac{17}{32}$″ below *b′d′* and above *a′c′* draw the horizontal lines *f′i′* and *e′h′* respectively. Draw the dotted vertical lines *egln*, *fhmp*, *b′a′*, *d′c′*, *f′e′*, and *i′h′*, by projecting the inner full and the two dotted circles in the plan. Join the dotted lines by semicircles with a radius of $\frac{1}{16}$″, as shown. Instead of drawing a side view of this object, which would be the same as the front view, we draw a section of it, which is obtained by imagining the object cut along the line *AB*. This view is the same as the front view, with the exception that all the dotted lines in the latter are full lines in the section. Draw the center line *EF* and make the section the same as the front view, with the above exception. The sectioning will be explained in **Art. 55.**

All the figures up to this point have been drawn full size, that is, the dimensions of the object have been represented in their true lengths on the drawing. The remaining figures, however, are drawn to a scale of 3″ to 1 ft., or $\frac{1}{4}$ size, and that part of the scale representing this relation should be used. The manner of using the scale has been explained in **Art. 20.**

Fig. 8 represents a **square, cast-iron washer** of the dimensions shown on the drawing. First draw the center lines *AB* and *CD*. 5″ above and below *CD* draw the horizontal lines *bd* and *ac* respectively, and join these by the vertical lines *ab*, 5″ to the left, and *cd*, 5″ to the right of *AB*. This will give a square each side of which is 10″. In a similar manner draw a square within the larger one, each side of which is $4\frac{1}{8}$″, and one within this one, each side of which is $2\frac{1}{8}$″. Using the point of intersection of *AB* and *CD* as a center, describe a circle $1\frac{1}{4}$″ in diameter. This completes the top view or plan. To draw the front view, draw the base line *ef* of indefinite length, and $\frac{1}{2}$″ above it the line *gh*. Join these by the lines *ge* and *hf* by projecting *a* and *c*. Draw

the horizontal dotted line *ns* $1\frac{1}{8}''$ above *ef*, and *ik* $\frac{1}{2}''$ above *ns*. Draw the dotted lines *ln* and *os* by projecting b' and d', and the dotted lines *ru* and *tv* by projecting the circle in the plan. Locate the points *i* and *k* by projecting a' and c', and draw vertical lines through *i* and *k* meeting the line *ns* (prolonged). Join these points of intersection with *g* and *h*, and join these lines with those through *i* and *k* by small arcs as shown.

Fig. 9 represents a **90° pipe elbow** drawn to a scale of $3'' = 1$ ft. As will always be done hereafter, the two views will be drawn together—that is, one view is not to be completed before the other one is begun. First draw the horizontal lines *abop* and *ders* of indefinite length, $\frac{7}{8}''$ apart, and taking any point, *c*, on the line *abop* as a center, describe the center line *EA* with a radius of 8″. Draw a vertical line *gf* through the point *c*, of indefinite length, and $\frac{7}{8}''$ to the left of it, the line *ih*. From *A*, where *EA* cuts *gf*, continue the center line *EA* by drawing the horizontal line *AB*, and at a convenient distance from *A* draw the vertical center line *CD*, intersecting *AB* at *O*. From *O* as a center describe the following circles: One with a diameter of $11\frac{1}{2}''$ for the exterior of the flange, one with a diameter of $9\frac{1}{2}''$ for locating the centers of the holes in the flange, a dotted circle with a diameter of $6'' + \frac{3}{4}'' + \frac{3}{4}'' = 7\frac{1}{2}''$ for the exterior of the pipe, and one with a diameter of 6″ for the interior of the pipe. Where these circles intersect the center line *CD*, points will be found which are projected on the line *gf*, giving the points *g*, o', *l*, *n*, t', *f*. With *c* as a center, and radii equal to co', *cl*, *cn*, and ct', describe quadrants $o'n'$, *lk*, *mn*, and $t'u'$; *lk* and *mn* being partly dotted, as shown. Join the two outer quadrants to the inner faces of the flanges by small arcs with $\frac{1}{4}''$ radius, as shown in the figure. On the circle, with a diameter of $9\frac{1}{2}''$ in the front view, step the radius off six times, beginning on the line *CD*. With these points as centers, describe six circles $\frac{7}{8}''$ in diameter. Project these on the line *gf* and draw the horizontal lines joining *gf* and *ih*. Two of the holes are indicated by full lines and two by dotted lines, as part of the elbow is shown in section, the section being taken through *CD*. With *c* as a center, and

radii equal to the distances from c to the points just located on gf, mark similar points along the line ab. Join these points by vertical dotted lines to de. Draw the center lines for the holes in a similar manner. Draw the lines tu, $f'e'$, $i'l'$, and vw. Join tu and vw to rs by fillets (arcs), as shown. Draw the vertical lines ro, sp, and the dotted lines representing the holes in the flange $rosp$. The lines xy and $x'y'$ are drawn free-hand, and show how the front part of the pipe is broken away.

Fig. 10 represents a **connecting** (con-nect'ing) **rod** drawn to a scale of $3'' = 1$ ft., a side view being shown below and a top view above. Draw the center lines AB and CD. Draw bd and ac equally distant from the center line, $3\frac{1}{2}''$ apart, and fh and eg $6\frac{1}{2}''$ apart. Equally distant from CD, $2\frac{1}{2}''$ apart, draw the lines $b'd'$, $a'c'$, $f'h'$, and $e'g'$. Draw the vertical line $aba'b'$, and $6\frac{1}{8}''$ from it $cdc'd'$; $18\frac{1}{8}''$ to the right of this draw the line $efe'f'$, and $6\frac{1}{8}''$ from this the line $ghg'h'$. Draw the central part in the top view by drawing two horizontal lines $1\frac{1}{4}''$ apart, joined to the two ends just drawn by fillets. The side view of this is drawn by measuring off $2\frac{3}{4}''$ on cd, $\frac{1}{2}$ of it on each side of AB, and $4\frac{1}{4}''$ on fe. Join these points by lines, which are joined to the two ends drawn first by fillets, as shown. Draw the center line $EFE'F'$, and from the point where this intersects AB as a center, draw a circle $\frac{5}{8}''$ in diameter. $1\frac{7}{8}''$ to the left of $E'F'$, and $2\frac{3}{8}''$ to the right of it, draw center lines for two circles $\frac{3}{4}''$ in diameter. The three circles just drawn are projected, as explained before, the $\frac{5}{8}''$ hole only penetrating the object as far as the keyway, which is to be drawn next. Draw the vertical dotted line ij $\frac{1}{2}''$ to the left of EF; lay off the point l $\frac{1}{2}''$ to the right of EF on ac, and k $\frac{3}{4}''$ to the right of EF on bd. Draw the dotted line lk. On the top view draw the horizontal lines $i'k'$ and $j'l'$, equally distant from CD, $\frac{7}{8}''$ apart. Join them by the lines $i'j'$, $o's'$, and $k'l'$, by projecting i, l, and k. The construction at the right end being very similar to that at the left, no further description is necessary. The keyway is $1\frac{1}{2}''$ at the top, and the center line $2\frac{9}{16}''$ from gh.

This completes the description of the figures on this plate,

which should not be inked in until the following articles have been read.

53. Rules for Inking. As has been stated before, the order in which a drawing is made has a great deal to do with its neatness and the rapidity of its execution. The student should re-read Articles 33 and 50, and in inking the drawing follow the order given below, which has been found by experience to give the best results:

1. Circles. 2. Arcs. 3. Irregular curves. 4. Horizontal lines. 5. Vertical lines. 6. Oblique lines. 7. Clean the drawing lightly. 8. Horizontal center lines. 9. Vertical center lines. 10. Shade lines. 11. Section lines. 12. Dimension lines. 13. Dimensions. 14. Title and name. 15. Clean drawing.

The student should never depart from this order, and he will find that the close observance of these rules will give him satisfactory results. Again, let us remind him to have the pen-leg of his compasses perpendicular to the paper; to stop the arcs at the proper place; to observe the rules about drawing irregular curves; not to have the ink in his pen give out before a line is completed; to draw all vertical lines, even the working edges, with a triangle; not to erase his ink lines when cleaning the drawing; to use the right lines for the purposes for which they are intended; to read the articles on shading, sectioning, and dimensions, which follow; to make his numbers and letters neatly and space the title properly; not to put the reference letters on the drawing used in describing the figures; to clean his drawing after it is completed; and to write his name and address in pencil on the back of the sheet before he mails the drawing to us.

54. Rules for Shading. Shade lines are used on drawings to aid the workingman in getting a clearer idea of the shape of an object by looking at the drawing, and to improve the general appearance by making the objects appear as they do with their natural lights and shades. Shading outline drawings is not a universal custom, and in some drawing rooms all drawings are shaded, while in others shading is omitted entirely. We therefore deem it necessary for our

students to have a knowledge of the principles of shading, so that they may be in a position to apply them when required. As many authorities differ regarding the purely conventional method of shading drawings, we have adopted that style which is by far the simplest to understand, and the one which gives the most natural appearance to the drawings of the objects.

We assume the light to come from the upper left-hand corner of the drawing, parallel to the plane of the paper, making an angle of 45° with all horizontal and vertical lines. This direction of the light is assumed to remain the same for all views, and does not vary its direction whenever the object is drawn in a different position. By imagining a series of parallel lines making an angle of 45° with all horizontal and vertical lines to strike the object, we can determine those surfaces that are touched by these lines and those that are not. The former are called **light surfaces,** and the latter **dark surfaces.**

While no definite rules can be given for shading very complicated objects, or objects in oblique positions, we shall lay down the following rules for shading, which, however, cannot be strictly adhered to, and may even be violated for the sake of appearance in some of the drawings in this course:

1. All edges formed by the intersection of two dark surfaces are shaded, that is, the lines are to be drawn heavy.
2. All edges formed by the intersection of a light and a dark surface are shaded.
3. All horizontal base lines are shaded.
4. All horizontal top lines are light.
5. All right-hand vertical lines whose projections are perpendicular to horizontal lines in the plan or elevation are shaded.
6. All left-hand vertical lines whose projections are perpendicular to horizontal lines in the plan or elevation are light.
7. All surfaces parallel to the paper are light surfaces.

Referring to Drawing Plate, Title: Projection, the above rules are applied in the following manner:

Rule 1. The line *bt* in Fig. 5 and *c′c* in Fig. 8.

Rule 2. The line *ms* in Fig. 3 and *bc* in Fig. 6.

Rule 3. The line *ab* in Fig. 1 and *op* in Fig. 9.
Rule 4. The line *cd* in Fig. 2 and *fh* in Fig. 10.
Rule 5. The line *dc* in Fig. 7 and *hf* in Fig. 1.
Rule 6. The line *ab* in Fig. 8 and *ef* in Fig. 10.
Rule 7. The surface *abcd* in Fig. 1 and *rspm* in Fig. 3.

To further illustrate the use of these rules and their application to the shading of circles, let us refer to Fig. 66.

ABCD is a square block with a square projection or boss at *a*, a square hole at *b*, a circular boss at *d*, a circular hole at *e*, and a circular boss with a square hole at *c*. The arrows show how the light strikes the various surfaces, exterior and interior, and at a glance a person can see why the figure is shaded as shown.

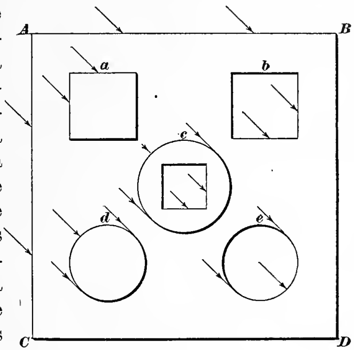


Fig. 66.

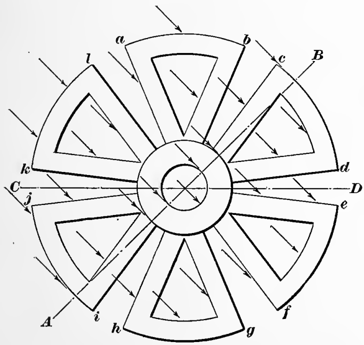


Fig. 67.

While this figure illustrates the shading of horizontal and vertical lines, Fig. 67 shows how oblique lines are shaded. In this figure we have six triangular pieces, raised above the paper, the interior of them being cut out as shown. The central part is a hollow cylinder, also raised above the paper and above the triangular pieces just mentioned.

The arrows indicate the direction of the light, and the

student will notice that it is tangent to the four circles at the points where the line AB cuts the circles. This line makes an angle of 45° with the horizontal center line CD. He will also notice that the piece bounded by the arc kl has its two exterior edges shaded and its two interior ones light; the reverse is the case with the piece bounded by ef. This is a case which does not arise frequently, but shows the necessity of considering each surface separately before shading the edges which bound them.

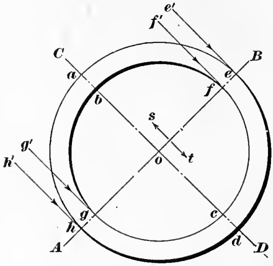


FIG. 68.

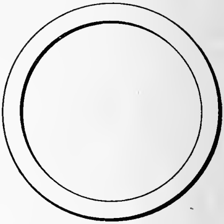


FIG. 69.

Fig. 68 illustrates the method of shading circles. The lines AB and CD make angles of 45° with the horizontal. The light comes in a direction parallel to CD and illuminates the upper half of the ring, and does not reach the lower half, that is, the part below AB. The reverse takes place with the inner circle, and the shaded portion of this circle will therefore be above the line AB. In other words, the rays of light $e'e$, $h'h$, and $f'f$, $g'g$ are tangent to the circles at the points where AB cuts the circles.

To shade the circles, the center o is moved along the line CD in the direction s or t, and, with the same radius that was used for describing the original circle, part of another circle is described on that side of AB which is to be shaded. This second circle will meet the original one at the points e, f, g, and h, and care should be taken not to extend it beyond the point of coincidence. The width of the shaded line is determined by the amount the center is shifted.

In shading concentric circles, such as are shown in Fig. 68, in which the distances *ab*, *ef*, *cd*, and *gh* are small compared with the diameters of the circles, it is very essential to move the center in such a direction as to keep the above distances equal. That is, for shading *aedh* the center should be moved in the direction *t*, so that the heavy line is on the outside of the circle; and for shading *bfcg* the center is moved in the same direction, so that the heavy line is on the inside of the circle. Fig. 69 shows how distorted the ring will appear if the center is moved in the direction *s*. In shading very small circles the heavy line should be put on the outside, so as to keep the interior space circular. However, the rule regarding the shading of concentric circles takes precedence of this one.

55. Sectioning. In the description of Fig. 7 on the plate entitled "Projection," we referred to the use of sections and how they are obtained. All parts of the object which are cut by the imaginary cutting plane are sectioned or filled out with section lines. These are drawn with the triangle at an angle of 45°. They are not penciled, but are inked in after the outlines of the figures have been drawn in ink and the drawing has been shaded. They are spaced by the eye and are a full $\frac{1}{32}''$ apart, or about three spaces to $\frac{1}{8}''$. For larger drawings the lines are drawn $\frac{1}{16}''$ apart. By means of sectioning we can further indicate the number of parts on an assembly drawing, as the different parts are sectioned in opposite directions. The material of which each part is made can be shown by adopting different styles of section lines. For cast iron, single light lines at an angle of 45°, the above-mentioned distance apart, are used. The styles adopted for sectioning other materials will be taken up in the next paper on drawing.

56. Dimensions. We may say that the most important element on a working drawing is the correct placing and completeness of its dimensions. If the workingman only had a rough free-hand pencil sketch to work from, he could construct the object, if all the dimensions were properly

marked on the sketch. The student should therefore pay particular attention to this portion of his work; and while he will only be expected to copy the dimensions on these plates, he should study the method employed, so that he will know how to place dimensions on working drawings later in his career.

No definite rules about the number and position of dimensions can be given, but in general we may say, insert all the dimensions that are required by a workingman or builder in order to construct the object by having reference to the drawing only, to place them where they are most liable to be looked for, to make the figures plain, to put the "over-all" dimensions on a drawing, and not to duplicate any dimensions.

The dimension lines are a series of dashes, as explained in **Art. 50** and illustrated in Fig. 65 by the line *ij*. The "over-all" dimensions, that is, those indicating the entire length of an object or a section of it, are generally placed on the exterior of the drawing, about $\frac{3}{16}''$ to $\frac{1}{4}''$ away from it. As will be seen by referring to the plate just drawn, the projection lines are frequently used as the limits for the dimension lines, as *ec* and *fd* in Fig. 1, or *ds* and *cv* in Fig. 7. The diameters of cylinders and cones can either be marked on the plan, as in Figs. 2, 4, and 7, or on the elevations. In the case of prisms and pyramids the diameters of the circumscribed circles are given, as in Figs. 3 and 5. The diameters of holes may either be marked on the elevation, as the $\frac{1}{2}''$ hole in Fig. 7, or within the circle in the plan, as the $1\frac{1}{4}''$ *d* hole in Fig. 8, or marked on the outside, as the $\frac{7}{8}''$ holes in Fig. 9, or as the $\frac{5}{8}''$ hole is marked in Fig. 10. It is customary to draw center lines and refer the dimensions of other parts to these, as the location of the line *EF* in Fig. 10, and then marking the distance between it and the line *ij* $\frac{1}{2}''$. When the space is too small for putting in the dimension lines and figures, put the lines and arrow-heads on the outside and the figures within the space, as the $\frac{7}{8}''$ dimension of the line *ig* in Fig. 9, or the $\frac{1}{2}''$ dimension in Fig. 10, just referred to. The radii of fillets are marked as in Fig. 7, front elevation, by writing $\frac{1}{16}''$ *r*, or without giving the length

of the radius and simply locating the center, as is done in Fig. 10, near the points d, e, d', e'.

Care should be taken to have the dimension lines touch the extension or limit lines, as is shown by the upper line in Fig. 70, and not like the lower line in the figure.

The arrow-heads should not open as they do on the line cd, but should be made neatly, as they are on ab. They, as well as the figures, are made with a Gillott No. 303 pen.

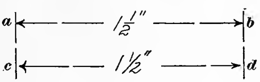


FIG. 70.

The figures should be legible and $\frac{3}{32}''$ high. The fractions are $\frac{5}{32}''$ high, as shown in Fig. 22, and the horizontal dividing line, which should always be used in a fraction, is in line with the dimension lines. The numerator and denominator are placed under each other in a slanting direction, the slant being the same as that of the whole numbers.

PLATE VII.—TITLE: PROJECTIONS AND CONIC SECTIONS.

57. The objects drawn on Plate VI. were so placed that the center lines, and at least one flat surface of each, were parallel to the plane of the paper. The placing of objects in this convenient position for drawing them is only possible when the objects are small, or if the details of a large object are drawn separately; but when it is required to make a drawing of the assembled object, the various parts may be located in such positions as to have their center lines make angles with the plane of the paper and have none of their surfaces vertical or horizontal. In order to prepare the student for these cases, the objects drawn on this plate are all placed, or cut by planes, at an angle, and this gives rise to certain constructions not necessary on Plate VI. The principles involved in this plate, and the one preceding and following it, should be thoroughly understood by the student, as they are fundamental and will be continually applied in the plates which follow.

Fig. 1 represents a **rectangular prism** $2\frac{1}{4}''$ long, $1\frac{1}{4}''$

wide, and $\frac{7}{8}''$ thick, the $1\frac{1}{4}''$ sides making an angle of 20° with a horizontal line. There is a projection on one side of the prism, as shown. The front elevation is drawn first, because in that view only, are all the lines drawn in their true lengths. The drawing is made full size. Draw the line *ad* of indefinite length, making an angle of 20° with a horizontal line *ap'*. From the point *a*, where *ad* intersects the horizontal line, draw the line *ab* perpendicular to *ad* of indefinite length. Draw *cd* parallel to this line and $1\frac{1}{4}''$ from it. Join these lines by the line *bc*, parallel to *ad* and $2\frac{1}{4}''$ from it; $\frac{1}{2}''$ from the line *bc* and parallel to it, draw the line *ef*. Draw *gh* parallel to *ef* and $\frac{5}{8}''$ from it. Join these lines by *fh* parallel to *cd* and $\frac{1}{4}''$ from it. This completes the front elevation. To draw the plan, draw two horizontal lines, *im* and *jn*, $\frac{7}{8}''$ apart, and join them by the lines *ij*, *kl*, *mn*, obtained by projecting the points *b*, *c*, and *d* respectively, on the line *ikm;* $\frac{1}{4}''$ from *im* draw the horizontal line *ot* and the line *pu* parallel to, and $\frac{3}{8}''$ from *ot*. Join them by the lines *op*, *rs*, and *tu*, obtained by projecting the points *e*, *f*, and *h* on the line *ot*. To draw the side view, first draw the vertical lines *a'c'*, *g'f'*, *u't'*, and *p'o'* the given distances apart. Then join these by horizontal lines as shown, by projecting the points *a*, *d*, *g*, *h*, *f*, and *c*.

Fig. 2 represents a full-size drawing of a **hexagonal prism** having two of its parallel sides parallel to the plane of the paper, the base of the prism making an angle of 20° with the horizontal. Draw the line *ad*, making an angle of 20° with the horizontal; 2″ from *ad* and parallel to it, draw the line *bc* of indefinite length. From the point where *ad* intersects the horizontal, draw a line *dc* perpendicular to it. Draw the center line *AB* parallel to *dc* and $\frac{5}{8}''$ from it. From the point *l*, where *AB* intersects the line *bc*, as a center, and with a radius of $\frac{5}{8}''$, describe a semicircle cutting the line *bc* in *b* and *c*. Divide the semicircle into three parts, *bi*, *ij*, and *jc*, by stepping off the radius three times around the semi-circumference. Draw the lines *jg*, *ie*, and *ba* parallel to *AB*. To draw the top view or plan, draw the horizontal center line *CD* and the vertical center line *EF* by

projecting the center l. From the intersection of CD and EF, lay off the distances or and os equal to if or jh, and through these points draw the horizontal lines tu and vw of indefinite length. The points n, v, t, m, y, p, w, u, and k are obtained by projecting the points a, e, b, f, h, and c respectively. Join the points thus obtained by lines as shown on the drawing. This completes the top view. To draw the side view, first draw the center line GH. Lay off a distance on each side of it equal to or or os and draw the vertical lines $f'g'$ and $i'y'$. On these lines and on GH locate the points b', f', i', h', e', c', g', y', and d' by projecting the points b, f, h, c, g, and d respectively. Join the points by lines as shown in the figure.

Fig. 3 represents a full-size drawing of a **cylinder,** $1\frac{7}{8}''$ long and $1\frac{1}{4}''$ in diameter, whose base makes an angle of 20° with the horizontal. It is drawn similarly to Fig. 2 by first drawing the lines ad, bc, cd, and AB. Then describe the semicircle $befc$ and divide it into any convenient number of equal parts, with a 60° triangle, six in this case. Project these points on bc parallel to AB and obtain the points b, i, j, k, l. Draw ba, which completes the front view. To draw the top view or plan, draw the center lines CD and EF and lay off om and on equal to hA, or $\frac{5}{8}''$, and draw the horizontal lines $r'm$ and $p'n$. Also draw the horizontal lines $j'k'$ at a distance from CD equal to je or kf; also $i'l'$, equal to is or lg. Project the points b, i, j, k, l, c, upward, and these intersect the lines just drawn at the points b', i', j', k', l', and c'. Through these points draw a curve with the irregular curve. Project the point t on the lines $r'm$ and $p'n$, and a on the line CD, and through r', a', p' draw a curve in the same manner as $mb'n$ was drawn. This completes the top view. To draw the side view, first draw the center line GH, and draw the vertical lines rt' and pt' of indefinite length, at a distance equal to om or on on each side of it. Draw the center line KL by projecting the point h. Draw the lines $e'e'$ and $g'g'$ at a distance from GH equal to that of the point k' from CD, and $d'd'$ and $f'f'$ equal to the distance of the points l' from CD. Project the points b, i, j, k, l, c to the right, and where these lines intersect the lines just drawn, we get the

points e', d', n', f', g', and m'. Through these, draw an ellipse with the irregular curve, and in the same manner draw a curve through the points $t'd't'$ obtained by projecting the points t and d.

Fig. 4 represents a full-size drawing of a **truncated** (trun'ca-ted) **pentagonal pyramid** standing on its base, the cutting plane making an angle of 30° with the horizontal. Draw the center lines AB and CD, and from the point o, where these intersect, as a center, describe a circle with a radius of $\frac{13}{16}''$. Within this describe a regular pentagon, the lower side of which is a horizontal line. Draw the horizontal line al of indefinite length and on it project the points a', h', g', and c', giving the points a, h, g, and c. Join these points with the vertex b, located on the center line AB, $2\frac{1}{4}''$ above al, by drawing the lines ab, hb, gb, and cb. Draw the line dj, representing the cutting plane, cutting AB at a point $\frac{7}{8}''$ above the base line, and making an angle of 30° with the horizontal. The line dj cuts the lines just drawn in d, e, f, i, and j. Project these points on the lines oa', ob', oc', og', and oh', and join the points d', f', j', i', and e'. This completes the top and front views. To draw the side view, first draw the center line EF perpendicular to al. Project b on EF; make vk equal to ok', vl equal to ob', and vm equal to $m'c'$, and draw kt, mt, and lt. On these lines project the points d, e, f, i, and j, and join the points p, r, s, n, o by lines as shown in the figure.

Fig. 5 represents a full-size drawing of a **90° square elbow** standing on one of its legs. The top and front views at the left show the elbow in a position with the front surface parallel to the paper, this surface making an angle of 25° with the horizontal in the views at the right. The front view at the left is required in order to draw the front view at the right, and the top view at the left is reproduced at the right, being placed at the given angle. Draw the line an of indefinite length, fe, $1\frac{1}{8}''$ above it, and cd, 1″ above that. Then draw $a'e'$ and $c'd'$, 1″ apart, and draw the vertical lines $aca'c'$, $bfb'f'$, and $ede'd'$, 1″ and $\frac{5}{8}''$ apart respectively. Draw the dotted lines ij, ik, gy, gh, $i'j'$, $j'k'$, and $i'y'$, $\frac{3}{16}''$ from the lines parallel to them; draw $g'h'$ by projecting the line gh.

To draw the views at the right, first redraw the top view at the left by placing it in the position $l'w't'v'$, the line $i'v$ making an angle of 25° with the horizontal. The front view at the right is obtained by projecting the horizontal lines of the front view at the left for the horizontal lines and the points on the right-hand top view for the vertical lines, as the projection lines on the drawing clearly show.

Figs. 6, 7, and 8 represent what are called **conic** (con'ic) **sections.** These are figures obtained by cutting a cone by a plane. If a cone is cut by a plane through vertex and base, the section will be a **triangle,** and if cut by a plane parallel to its base, the section will be a **circle.** If an oblique plane cuts the cone above its base, the section will be an **ellipse,** as shown in Fig. 6. A **parabola** (par-ab'o-la) is a figure obtained by a plane cutting a cone parallel to one of its sides, as in Fig. 7. An **hyperbola** (hy-per'bo-la) is obtained when the cutting plane makes any angle with the base greater than that made by a side of the cone (see Fig. 8).

Fig. 6 represents a full-size drawing of a cone which has been cut by a plane making an angle of 30° with the horizontal. Draw the center lines AB and CD, and from o, their point of intersection, as a center, describe a circle with a radius of $\frac{3}{4}''$. Draw the line ag of indefinite length, and on it project the points a' and c'. Join a and c with a point b, on AB, $2\frac{1}{4}''$ above ac. Through i on the line AB, draw the line de, $\frac{7}{8}''$ above ac, making an angle of 30° with the horizontal. Divide the circle in the top view into twelve equal parts with the 60° triangle as shown, and draw radial lines to the center, o. Project the points on the circumference on the line ac, giving the points j, k, etc. Draw lines from these points to the vertex b, cutting the line de in the points n, o, r, and s. Project these points up, cutting the radial lines in the points d', n', o', r', s', and e', and make oi' equal to il. Through these points draw an **ellipse** with the irregular curve.

To draw the side view, first draw the center line EF, and on it project the point b, giving the point h. Make fg equal to ac, and draw fh and gh. Lay off vu and vm equal to the perpendicular distances from the center line CD to u' and m'

respectively, in the plan, and lay off the same distances on *vg*. Draw lines joining these points with the point *h*. Project the points *i*, *o* and *r*, *n* and *s*, *d* and *e*, on the lines *fh*, *mh*, *uh*, and *vh* respectively, continuing these projection lines till they cut similar lines on the other side of *vh*. Through the points i'', o'', r'', n'', s'', d'', e'', etc., draw an **ellipse** with the irregular curve.

Fig. 7 represents a full-size drawing of a cone cut by a plane parallel to one of the sides. First draw the center lines *AB* and *CD*, and with their point of intersection *o*, as a center, describe a circle $1\frac{1}{2}''$ in diameter. Draw the line *ak* of indefinite length, and on it project the points a' and c'. Join *a* and *c* with the point *b* on the line *AB*, $2\frac{1}{4}''$ above *ac*. Draw the line *ei* parallel to the side *bc*, cutting the center line *AB* at *h*, $\frac{11}{16}''$ above *ac*. Divide the circle in the plan into twelve equal parts with the 60° triangle, as shown, and draw radial lines to the center *o*. Project the points on the circumference on the line *ac*, giving the points *f*, *g*, etc. Draw lines from these points to the vertex *b*, cutting the line *ei* in the points *r* and *s*. Project the points *e*, *r*, and *s* up, cutting the radial lines in e', r', and s', the projection of the point *i* cutting the circle in the points i'. Make oh' equal to *hj* in the front elevation and join the points i', h', s', r', and e' with an irregular curve, $i'i'$ being a vertical line. To draw the side view, first draw the center line *EF*, and on it project the point *b*, giving the point *l*. Make *dk* equal to *ac* and draw *dl* and *gl*. Make *vw*, *vn*, and *vu* equal to the perpendicular distances from the center line *CD* to the points w', n', and i' respectively, repeating this construction on the line *vg*. Join these points with the vertex *l*. Project the points *e*, *r*, *s*, and *h* on the lines *lv*, *lw*, *ln*, and *ld* respectively, giving the points e'', r'', s'', and h''. Through these points draw a **parabola** with the irregular curve, terminating in the points *u* and *x* on the line *ag*.

Fig. 8 is a full-size drawing of a cone cut by a plane making a greater angle with the base than that made by the sides. The plane is parallel to the axis *AB*. Draw the plan, front and side elevations of the cone as in Figs. 6 and 7, the diameter of the base being $1\frac{1}{2}''$, and the height $2\frac{1}{4}''$. Again

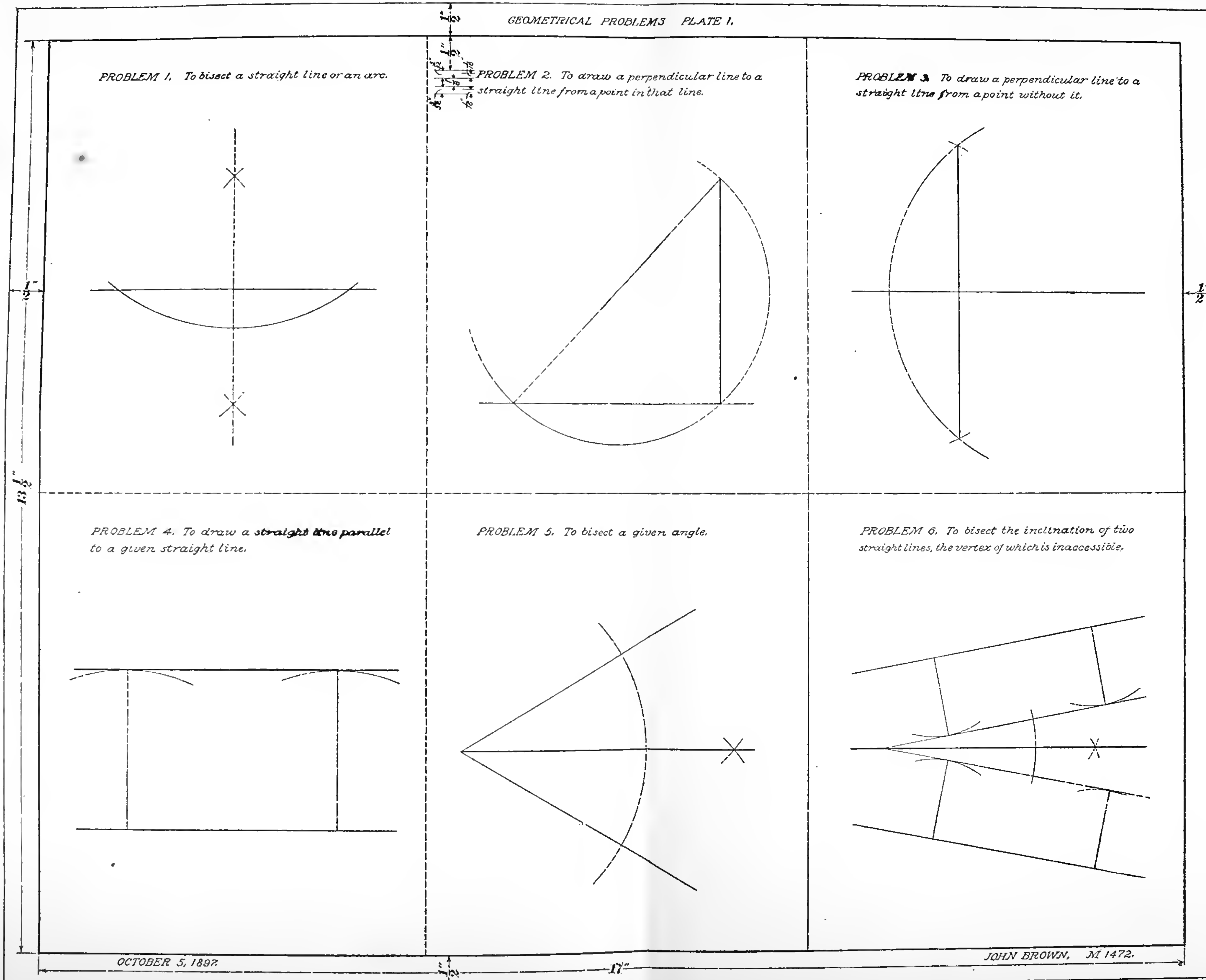
divide the circle into twelve parts; project the points on the circumference on the line *ac*, and join the points, *e*, *f*, etc., with the vertex, *b*. Draw the vertical line *ed*, $\frac{1}{4}''$ from *AB*, and project it upward, getting the line *e'f'*. To complete the side elevation, lay off the points *i*, *n*, and *r* as in Figs. 6 and 7, and draw the lines *hr*, *hn*, and *hi*. On these lines project the points *d*, *x*, and *u*, and through the points *d'*, *x'*, *u'*, and *r*, draw an *hyperbola* with the irregular curve.

Fig. 9 represents a full-size drawing of a **triangular prism with two projections** of the given dimensions, the base of the prism being parallel to the paper, and the long edges making an angle of 20° with the horizontal. First draw the top view at the left by drawing the lines *ac* and *bd* $1\frac{3}{4}''$ apart, making an angle of 20° with the horizontal. Draw *ab* and *cd*, $2\frac{1}{4}''$ apart, and perpendicular to these lines. Draw *ef* midway between *ac* and *bd* and parallel to them. $\frac{1}{4}''$ from *ab*, and parallel to it, draw the line *gj*; $\frac{3}{8}''$ from this, the line *ik*, and $\frac{3}{8}''$ from this, the line *hl*, all parallel to *ab*, and of indefinite length. Draw *gh*, $\frac{1}{8}''$ from *bd* and parallel to it; $\frac{5}{16}''$ from this line on *hl* locate the point *l*; $\frac{1}{8}''$ from *ef* and parallel to it draw the line *mn*, and $\frac{1}{2}''$ from it and parallel to it the line *op*. Draw the line *np* parallel to, and $\frac{3}{8}''$ from *dc*, and $\frac{5}{8}''$ from it and parallel to it, the line *om*. This completes the top view with the exception of the lines *jk* and *kl*, which cannot be drawn until the point *k* is located. This requires the drawing of an end view. Draw the vertical line *c'b'* of indefinite length; $\frac{13}{16}''$ from it and parallel to it draw the line *f'b''* of indefinite length, and $\frac{1}{4}''$ from it, the line *p'm'* of indefinite length. On the line *f'b''* project the points *f* and *e*, and on *b'c'* project the points *c*, *d*, and *b*. Draw *b'b''*, *d'f* and *c'f'*. To project the point *h*, *l*, and *n*, we draw lines parallel to *bd*, which intersect *fd* in *h'*, *j'* and *n'* and the line *f'd'* in *h''*, *l'*, and *n''*. From these points draw lines parallel to *b'd'*, giving the lines *h''g'*, *l'g''* and *n''i'*. On these lines project the points *g*, *i*, *h*, and *l*, giving the points *g'*, *g''*, *i'*, *s*, *s'*, *r*, and *l''*. Draw the lines *g'g''*, *g''i'*, *i's*, *ss'*, *s'r*, and *rl''*. Project the point *l''* on *ik*, giving the point *k*, and draw the lines *jk* and *lk*. Project the points *m*, *n*, and *p* on the

line $p'm'$, giving the lines $m'm''$, $k'k''$, and $p'p''$. Draw the line $k''v$ parallel to $d'f'$.

Fig. 10 represents a **wrought-iron jaw** of the given dimensions drawn to a scale of $6'' = 1$ ft. To draw the front view, first draw the center line EF, making an angle of 20° with the horizontal, and AB perpendicular to it. Draw ab parallel to, and $1''$ below EF, ls and rp, $\frac{3}{4} \div 2 = \frac{3}{8}''$ on each side of EF and parallel to it; cd parallel to, and $2\frac{1}{4}''$ above ab, ef parallel to, and $1''$ above cd, and gh parallel to, and $1''$ above ef. These lines are joined by ge and hf, ea and fb, ci and dj, parallel to AB, and $1\frac{7}{8}''$, $2\frac{1}{4}''$, and $1\frac{1}{4}''$ apart respectively. Round the corners by small arcs, as shown. To draw the side view, first draw the vertical center line CD, and parallel to it draw the lines $v'f'$, $2''$ apart. Project the points f and o, and draw the lines $o'f'$ $1\frac{7}{8}''$ apart; draw the arcs at the points f'. To draw the curves $o'h'o'$, $v'b'v'$, $v'j'v'$, $v'C'v'$, $i'e'g'$, etc., we make use of constructions similar to the one shown in Fig. 3. Draw the quadrants hk and $r's'$, divide each into any number of equal parts—three in this case; project the points on the arc hk on oh, giving n and m. Project o, n, m, and h to the right, and the points on the arc $r's'$ upward. Where these intersect, we get the points h', m', n', and o', and through these points the curve $h'm'n'o'$ is drawn. A similar construction is used for the curves below, and the student should study the principle thoroughly, for it will be used very frequently in this course and in practice.

Fig. 11 represents a **base of a cast-iron column** drawn to a scale of $1\frac{1}{2}'' = 1$ ft. To draw the front view at the left, we first draw the line ab, making an angle of 60° with the horizontal. Draw the center line AB perpendicular to ab, at a convenient distance from the point a. From the point o, where ab and AB intersect, as a center, and with a radius of $9\frac{1}{2}''$, describe a semicircle $befa$. Divide this into 3 equal parts with your 60° triangle, and draw the semi-hexagon $befa$. Draw the line cd parallel to ab and $2''$ from it. Project the points e and f on ab, and draw the lines gi and mn. With o as a center, and radii of $1\frac{1}{2}''$ and $2\frac{1}{2}''$ respectively, describe two circles, about which two semi-hexagons are circumscribed. Project the points h, v, x, j, l, p, etc., perpendicularly


GEOMETRICAL PROBLEMS PLATE I.
PROBLEM I. To bisect a straight line or an arc.
PROBLEM 2. To draw a perpendicular line to a straight line from a point in that line.
PROBLEM 3. To draw a perpendicular line to a straight line from a point without it.
PROBLEM 4. To draw a straight line parallel to a given straight line.
PROBLEM 5. To bisect a given angle.
PROBLEM 6. To bisect the inclination of two straight lines, the vertex of which is inaccessible.
1/2"
13 1/2"
17"
OCTOBER 5, 1897.
JOHN BROWN, M 1472.

on ab, and continue the lines to the points r, k, t, y, z, u, w, s, joining these points by the broken line rs. To draw the ribs, we complete the dotted plan to the left of ab by drawing a line parallel to ab, $\frac{1}{2}''$ from it, and drawing the ribs between v and e, and x and f, $1''$ in width. Let us further illustrate the construction by referring to the rib $r'b'n's'$. Project the points r', s', and n' on the line cd, giving the points u' and v' and the line $t'f'$. Locate n' on the line $n't$, $6\frac{1}{2}''$ above cd, and obtain the point e' by projecting b'. To draw the end view at the right, first draw the center line CD. Parallel to it, and at a distance equal to om' on each side of it, draw the lines $s''m''$, the points s'' and m'' being found by projecting the points i and m. Project the points n, a, and c, locating the points n'', a' and c'', and draw the lines $a'm''$, $c''n''$, and $s''l''$. Lay off $2\frac{1}{2}''$ on each side of CD, equal to the distance oo' in the front view, and draw the vertical lines $l''h''$. Make part of CD a full line, as shown; also draw $y'z'$ parallel to, and $1''$ from $l''u''$. On these lines project the points r, k, t, y, z, u, w, s, and draw $t''r''$, $t''u''$, $u''s'$, $k'y'$, $y'z'$, and $z'w'$. Project h' on $h''l''$ and get the point h'', and d' on $n''c''$ and get d''. Project b' to the right and draw a line from d'' parallel to $c''n''$ (on the right side of CD), intersecting the projected line in b''. From b'' draw a line parallel to $c''n''$ (on the left side of CD). Project the point p', and this is intersected by a vertical line from b'' in p''. Join d'' and p'' by the line $d''p''$, and draw a line parallel to this from i', the projection of i' on $s''m''$. Draw $h''p''$ and $i''d''$. This completes the projection of one of the ribs. The others are projected in a similar manner, and the width of the one in front is $1''$, as is shown in the front view. The broken part of the column is sectioned to represent cast iron.

PLATE VIII.—TITLE: INTERSECTIONS AND DEVELOPMENTS.

58. Fig. 1 represents a full-size drawing of **three intersecting cylinders,** the axes intersecting at right angles and at an angle of 45° respectively. First draw the center lines AB and CD, and with their point of intersec-

tion o as a center, describe a circle $1\frac{3}{8}''$ in diameter. Project this downward and draw the front view of the cylinder $abcd$, $2\frac{1}{2}''$ in length. $1\frac{1}{4}''$ above the base ac draw the center line GH perpendicular to AB, and draw the horizontal lines eg and fh, $\frac{7}{8}''$ apart, joined by the vertical line ef, $\frac{3}{4}''$ from ab. From a point $\frac{9}{16}''$ above ac, on AB, making an angle of 45° with it, draw the center line EF. Parallel to this draw the lines ik and jl, $\frac{5}{8}''$ apart, jl being $1\frac{1}{2}''$ in length. Join these lines by kl perpendicular to them. Again referring to the plan or top view, draw the horizontal lines $e'm''$ and $f'm'$, $\frac{7}{8}''$ apart, and draw $e'f'$ by projecting ef. Draw $h'o'$ and $n'o'$, $\frac{5}{8}''$ apart. The ellipse $o''k'l'o''$ is obtained by the method shown in Fig. 3, Plate VII., and is again shown in this figure. To find the curves of intersection between the cylinders $abcd$ and $efgh$, describe the semicircle $e'yf'$ and divide it into any number of equal parts—six in this case. Project the points on the semi-circumference to the left and get the points t'', u'', g', n'', and x''. These projection lines cut the line $e'f'$ in points which are reproduced on ef, giving t, u, v, w, x. Project these horizontally to the right and the points t'', u'', g', n'', x'' downward, and through their points of intersection g, t', u', m, w', x', and h draw a curve. In a similar manner the projections of the points p, g, F, r, s cut the line kl in points which are reproduced on the perpendicular distance between the two lines $n'o''$ and $h'o''$ and are projected to the left, giving the points p'', g'', i', v'', s''. These are projected downward, and the points p, g, F, r, s are projected parallel to ki, and through their points of intersection, p', g', n, r', s', draw a curve, which will be the front view of the curve of intersection of the largest and smallest cylindrical surfaces in Fig. 1.

Fig. 2 represents the development of the cylinder $efgh$ in Fig. 1. Draw the horizontal line ab equal in length to the circumference of the cylinder $efgh$, which is equal to the diameter $\frac{7}{8}'' \times 3.1416 = 2.749''$, or nearly $2\frac{3}{4}''$. Draw the indefinite vertical lines ac and bd and divide the line ab into as many equal parts as the circumference of the cylinder was divided in Fig. 1—in this case twelve. Draw vertical lines through these points and make ac, jj', and bd equal to vm in

the front view; ee', ii', kk', and oo' equal to uu' or ww'; ff, hh', ll', and nn' equal to tt' or xx'; gg' and mm' equal to eg or fh. Connect the points c, e', f', g', h', etc., by using the irregular curve.

Fig. 3 represents the development of the cylinder $klij$ in Fig. 1. Draw the horizontal line ef equal in length to the circumference of the cylinder $klij$, or $\frac{5}{8}'' \times 3.1416 = 1.96''$, which is very nearly equal to $1\frac{31}{32}''$. Divide this line into twelve equal parts and draw twelve vertical lines as in Fig. 2. Make eg and fh equal in length to ik in the front view, and mn equal to jl. The distances on each side of mn are respectively equal in length to the perpendicular distances from the line kl to the points s', r', n, g', p'. Through the points thus obtained draw a curve.

Fig. 4 represents **three cylinders intersecting at angles of 45° and 30°.** Draw the vertical center line AB, db and ac parallel to it, $1\frac{1}{8}''$ apart and of indefinite length. Lay off $1\frac{7}{8}''$ on AB, giving the points C and E. Draw the center lines CD and EF, making angles of 45° and 30° respectively with AB. Draw be and af parallel to CD and make af $\frac{9}{16}''$ long. Draw ef perpendicular to CD. Draw dg and ch parallel to EF, making ch $\frac{15}{16}''$ long, and draw gh perpendicular to EF. Describe semicircles with o, o', and o'' as centers, as shown, and divide each one into six equal parts, projecting these points on the lines gh, dc, ba, and ef. This completes the front view of the cylinders. As will be noticed, the curve of intersection of cylinders of the same diameter is a straight line.

Fig. 5 shows the development of the three cylinders drawn in Fig. 4. The development of the end ba of the cylinder $abcd$ being the same as the end ba of the cylinder $baef$, but one curve need be drawn, the same being the case for the intersection dc. Draw ab equal in length to $1\frac{1}{8}'' \times 3.1416 = 3.534''$, or $3\frac{17}{32}''$ nearly, and divide it into twelve equal parts. Draw the vertical lines ac, ee', ff', gg', etc. Make ap, eg, fr, gs, ht, iu, jv equal to the distances from the line gh to the points d, p, h, E, i, j, c respectively, and reproduce the curve drawn through these points on the other side of the point v. Make pp', qq', rr', ss', tt', uu', vv' equal to the

distances *ca, jn, im, EC, hl, pk,* and *db* respectively, and reproduce this curve on the other side of v'. Then make $p'c$ equal to *be* in the front view and draw the horizontal line *cd*. The sections *apbo, pp'oo'*, and *p'co'd* are the developments of the cylindrical sections *dghc, abcd,* and *beaf* in the front view respectively.

Fig. 6 represents a cone cut by a plane making an angle of 30° with the axis of the cone. Draw the front view of a cone $2\frac{1}{2}''$ high, with a base whose radius is $\frac{7}{8}''$. Draw the line *CD,* making an angle of 30° with the center line *AB*, and 1″ above the base, measured on the center line. $\frac{1}{2}''$ above the point *g*, on the line *CD*, draw the line *EF*, which represents a plane cutting the cone parallel to the base. With *o* as a center, and a radius of $\frac{7}{8}''$, describe the semicircle *aAb*. Divide this into six equal parts; project the points on *ab*, and through them draw lines to the vertex of the cone, cutting *CD* in *c, e, f, g, h, i,* and *n*. Project these points on the line *bd*, giving the points c', e', f'. g', h', i', and *n*.

Fig. 7 represents the development of the frustrum of the cone *acbn* drawn in Fig. 6, and also of the frustrum *amrb*, whose upper and lower bases are represented by *mr* and *ab* respectively. Draw the center line *AB*, and with the point *o* as a center, and a radius equal to the slant height *bd* of the cone, describe an arc. The length of this arc is equal to the circumference of the base of the cone, and is obtained by stepping off on it the chords of the arcs *at, tu, uA,* etc., twelve times. If greater accuracy is required, the semicircle and the arc would have to be divided into a greater number of parts, or the method shown in Problems 23 and 24, Plate IV., should be used. From the points of subdivision of the arc draw lines to the center *o*. Make $aa'.cc'$, dd', ee', ff', gg', ii' equal bn, bi', bh', bg', bf', be', bc' in the front view respectively, and reproduce the curve drawn through the points a', c', d', e', f', g', and i' on the other side of the point i'. $aa'bb'$ represents the development of the frustrum *abcn*. From *o* as a center describe the arc *nst* with a radius equal to *dr* in the front view, *anbt* being a development of the frustrum *abmr*.

Fig. 8 represents a heptagonal pyramid cut by a plane

making an angle of 30° with the axis. Draw the center line AB, and about this line as an axis construct the pyramid abc of the given dimensions. Draw the line de, making an angle of 30° with the horizontal and cutting the center line at the point s, $\frac{7}{8}''$ above the base, and the horizontal line mn cutting AB, $\frac{5}{8}''$ above s. Project the points d, o, and r, which are the intersections of the lines ac, fc, and gc with de, on bc, giving the points d', o', and r'.

Fig. 9 represents the development of the frustrum $abde$ of the pyramid abc drawn in Fig. 8, and also of the frustrum $abmn$. Draw the center line AB, and with o as a center, and a radius equal to ac, the length of one side of the pyramid in Fig. 8, describe an arc. On this arc step off the distance ap, the length of one side of the heptagon, seven times, and draw the lines ao, bo, co, do, eo, etc. On these lines step off aa', bb', cc', dd', etc., equal respectively to bd', bo', br', and be in Fig. 8, and draw the lines $a'b'$, $b'c'$, $c'd'$, $d'e'$, etc., repeating the same construction on the other side of AB. $aa'm'm$ is the development required.

By laying off the distances af, bg, ch, etc., on the radial lines, all equal to the distance bn in Fig. 8, and drawing the lines fg, gh, hi, etc., we obtain $aflm$, which is the development of the frustrum $amnb$.

Fig. 10 represents a frustrum of a cone intersected by a cylinder, in plan and side elevation. First draw the center lines AB and CD intersecting at o. With this point as a center, describe two circles $2\frac{1}{4}''$ and $\frac{3}{4}''$ in diameter respectively. Draw the vertical lines ab and cd, $1\frac{1}{8}''$ apart, of indefinite length, and draw ac, $2\frac{7}{16}''$ below CD. Draw the vertical lines ef and gh, $2\frac{5}{8}''$ apart, and on these project the extremities of the vertical diameters of the circles in the plan, obtaining the points e, f, g, and h. Draw the lines eg and fh. Draw the vertical center line EF, $1\frac{5}{16}''$ from gh, and $a'm'$ and $c'i'$, $1\frac{1}{8}''$ apart, of indefinite length, joining them by $a'c'$ projected from the plan. Draw the semicircles aAc and $a'Fc'$, having ac and $a'c'$ as diameters respectively. Divide each semi-circumference into six equal parts and project these points upward by vertical lines of indefinite length. In the side view these lines intersect the centre line CD in the

points m'', v'', r'', d'', s'', n'', and i'', and the line eg in m', p, t, u, w, x, and i'. With o as a center, and radii equal to $m''m'$, $v''p$, $r''t$, $d''u$, $s''w$, $n''x$, and $i''i'$, describe arcs cutting similar vertical lines in the plan in m, k and v, p and r, b and d, j and s, b and n, and i respectively. Join these points with the irregular curve, the part bmd being full and bid dotted. Project the points m, v, r, d, s, n, and i to the right, cutting similar vertical lines in the side elevation in m', v', r', d', s', n', and i'. Join these points by a curve, as shown.

Fig. 11 represents the development of the cylinder drawn in Fig. 10. Draw the horizontal line ac and the two vertical lines ab and cd at a distance apart equal to the diameter $1\frac{1}{8}'' \times 3.1416 = 3.534''$, or $3\frac{17}{32}''$ nearly. Divide ac into twelve equal parts, to correspond with the number of divisions in the plan and elevation, and draw twelve vertical lines of indefinite length. Make ab', ee', ff', gg', hh', ii', oo' equal to the perpendicular distances of the points m, k, p, b, j, l, and i from the line ac in the plan respectively, and step off these same distances on the other side of the line oo'. Through these points draw the curve $bo'd$, and $abcd$ is the development of the cylinder $abcd$ in Fig. 10.

Fig. 12 represents the **end of a forked eye bolt** of the given dimensions. The upper left-hand view is a front view, to the right of it the side view, and below it the bottom view. Draw the center lines AB, CD, EF, and GH as shown, giving the points o, o', and o''. Draw the vertical lines $aba'b'$ and $cdc'd'$, $\frac{5}{8}''$ apart, $1\frac{1}{4}''$ from the latter the line $efe'f'$, and $\frac{5}{8}''$ from this the line $ghg'h'$. With z as a centre, located $1\frac{1}{4}''$ below CD on the line AB, describe a semicircle joining cd and ef, and with a radius of $1\frac{1}{8}''$ describe arcs terminating at z' and x on each side of the fork. With o' as a center, describe a circle $\frac{3}{4}''$ in diameter, and with a radius of $1\frac{1}{8}''$ arcs, which are joined by the horizontal lines kl $\frac{15}{16}''$ apart. Draw the horizontal lines $a'c'e'g'$ and $b'd'f'h'$, $1\frac{1}{2}''$ apart, and dotted horizontal lines $\frac{7}{8}''$ apart, as shown. Project the circle with a diameter of $\frac{3}{4}''$ upward, and join the points x and i by an arc having a radius of $1\frac{1}{8}''$. With o'' as a center, describe circles with diameters of $1\frac{1}{2}''$ and $\frac{7}{8}''$, and project these